NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

TACTICAL PLAN GENERATION SOFTWARE FOR MARITIME INTERDICTION USING CONCEPTUAL BLENDING THEORY

by

Kian Moh Terence Tan

December 2007

Thesis Advisor: John Hiles
Second Reader: Paul Shebalin

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2007	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Tactical Plan Generation Software for Maritime Interdiction Using Conceptual Blending Theory			**5. FUNDING NUMBERS**
6. AUTHOR(S) Kian Moh Terence Tan			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unliimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

This paper describes a plan generation software for maritime interdiction tactical operation using conceptual blending theory (CBT) and software blending mechanism. CBT explains how human think using mental spaces and mental operators. This paper uses CBT to model Boyd's Observation-Orientation-Decision-Act Loop Theory, a mental process used by military commanders to make decision. Bio-inspired operators are used to monitor cues from the real world. Expert's experiences were captured using a similar strategy implemented in the threat assessment model created by Liebhaber and Feher. Probability Estimates of Events (PEoE) are used to represent the significance of each possible tactic used by potential threats. Several PEoE are used to represent the mental patterns used to recognize a threat situation. Finally, decision is derived using linear assignment, an optimality approach that considers threat attack probability, goals and interdiction resource effectiveness. Experienced naval warfare officers have given positive feedback on the results presented and commented that the model resembles the cognitive process of a decision-maker in tactical plan generation. The model has also been tested in a Simkit-based simulator to coordinate patrol craft's maritime interdiction process.

14. SUBJECT TERMS Multi-Agent System, Conceptual Blending Theory, Plan Generation, Maritime Interdiction, Decision-Making, Software Blending, Threat Assessment			**15. NUMBER OF PAGES** 111
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

TACTICAL PLAN GENERATION SOFTWARE FOR MARITIME INTERDICTION USING CONCEPTUAL BLENDING THEORY

Kian Moh Terence Tan
Civilian, DSO National Laboratories, Singapore
BSc (Hons), University of London, 2000

Submitted in partial fulfillment of the
Requirements for the degree of

MASTER OF SCIENCE IN MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION (MOVES)

from the

NAVAL POSTGRADUATE SCHOOL
December 2007

Author: Kian Moh Terence Tan

Approved by: John Hiles
Thesis Advisor

Paul Shebalin
Second Reader

Rudy Darken
Chairman, Department of MOVES

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This paper describes a plan generation software for maritime interdiction tactical operation using conceptual blending theory (CBT) and software blending mechanism. CBT explains how human think using mental spaces and mental operators. This paper uses CBT to model Boyd's Observation-Orientation-Decision-Act Loop Theory, a mental process used by military commanders to make decision. Bio-inspired operators are used to monitor cues from the real world. Expert's experiences were captured using a similar strategy implemented in the threat assessment model created by Liebhaber and Feher. Probability Estimates of Events (PEoE) are used to represent the significance of each possible tactic used by potential threats. Several PEoE are used to represent the mental patterns used to recognize a threat situation. Finally, decision is derived using linear assignment, an optimality approach that considers threat attack probability, goals and interdiction resource effectiveness. Experienced naval warfare officers have given positive feedback on the results presented and commented that the model resembles the cognitive process of a decision-maker in tactical plan generation. The model has also been tested in a Simkit-based simulator to coordinate patrol craft's maritime interdiction process.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

With more than 60000 ships passing through Singapore each year, the Singapore Strait is among the most important waterways in the world [1]. The mission to closely investigate each vessel for terrorism or piracy activities is nearly impossible with just a few patrol craft and navy vessels. An automated decision support system will be useful to plan for the maritime interdiction resources with different capabilities for different maritime interdiction tasks.

The thesis aims to demonstrate an automated decision support capability using conceptual blending theory [26], [30] and software blending mechanism created by Professor Hiles at the Naval Postgraduate School [27], [32]. Conceptual Blending Theory explains how humans think using mental spaces and mental operators. This thesis uses Conceptual Blending Theory to model Boyd’s Observation-Orientation-Decision-Act Loop Theory, a mental process used by military commanders to make decision [13]. Recognition strategy [40] is used in the conduct of threat assessment and is implemented using bio-inspired operators [27] to monitor cues from the real world. Surface warfare experts’ experiences are captured using a similar strategy implemented in the threat assessment model created by Liebhaber and Feher [28]. Probability estimates of events are used to represent the significance of each possible tactic used by potential threats. Several estimates of events can be used to represent the mental patterns used to recognize a particular threat situation. This resembles the human’s inductive reasoning process using bounded rationality [35]. Finally, decision is derived using linear assignment, an optimality approach that considers threat attack probability, goals and interdiction resource effectiveness.

The simulated situational display, together with the threat assessment and decision suggested by the plan generation Software have been demonstrated to experienced naval littoral water surface warfare officers. Their feedback was encouraging and commented that such a decision support system will greatly assist decision makers in the maritime interdiction process. With this, the thesis has achieved its objective by using several novel theories to develop a plan-generation software design that resembles the cognitive process of a decision-maker. The thesis has also demonstrated a simplified form of adaptive display and proposed a way to represent a mental pattern of a particular situation. Such a mental pattern can be used to represent atypical situations, which an expert has never experienced before.

ACKNOWLEDGMENTS

This thesis required undivided attention and continuous research and development efforts. This thesis would not have been possible if not for my beloved wife’s continuous support and encouragement during this challenging period.

As a novice in computational cognition, this thesis is possible only with Professor Hiles’ patience guidance in building my foundation in biochemistry, Cognitive Blending Theory and bio-inspired operators. In addition to theory foundation, Professor Hiles has also provided valuable experiences and guidance in terrorist psychology, and guided me in the threat hypothesis and decision-making process.

This thesis requires expert knowledge in the littoral water warfare experience. Henceforth, this thesis will not be possible without Dr. Shebalin’s patience guidance in building the foundation in the maritime interdiction domain.

The simulator development would have been strenuous if Ng Chee Wan and Koh Kim Leng had not offered their simulator, complete with source codes, developed for SEA 10 project simulation.

I would also like to thank Dr Ciavarelli for his guidance in the literature survey and guidance in developing the verification and validation strategy.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PORT OF SINGAPORE

1. Singapore

In 2006, Singapore was the world's busiest port: the shipping tonnage hit an unprecedented 1.3-billion gross tons (GT) [1]. The container traffic reached 24.8 million Twenty-Foot Equivalent Units (TEUs), and the total cargo tonnage handled registered 448.2 million tons. This is not surprising since about 30 percent of the world's trade and 50 percent of the world's energy passes through the Straits of Singapore each year [2]. There are about two hundred shipping lines that converge in the Singapore Strait with links to more than six hundred ports in over a hundred and twenty countries. As a result, the littoral states of Indonesia, Malaysia, and Singapore are so important that they received international support from fifty countries and seventeen maritime-related organizations during the launch of the Co-operative Mechanism [3].

2. Piracy and Terrorism

However, this bloom in maritime traffic is complicated by occurrences of piracy. In the fall of 2005, the *Harvard Asia Quarterly* reported that piracy activities, some of which were related to terrorist networks, occurred on a daily basis in the region [5]. The *Quarterly* also emphasized that Southeast Asia is a "fertile ground" for piracy and estimated that piracy costs range from as low as US$250 million to US$16 billion a year. The Institute of Defence and Strategic Studies (IDSS) attributes the piracy activities to separatist groups in Indonesia. It reported that the Straits of Malacca and Singapore have a high risk of maritime terrorist attack due to the narrow waterways, high volume of maritime traffic, and the many ships that carry highly volatile or dangerous cargo [2].

Although maritime terrorism is unlikely, it would have a huge impact on "the transportation systems, and the possible economic consequences of a disruption of shipping traffic" [2]. Furthermore, Singapore is a prime terrorist target because more than 12,000 oil tankers and 3,000 chemical tankers call at Singapore each year, with a substantial amount of oil and chemicals [6]. Despite its vulnerability, however, the chief executive of the Singapore Maritime Port Authority (MPA) confirmed that MPA would ensure the safety and security aspect of the port [4]. In addition, America's war on terrorism has placed high emphasis on maritime security and plays a strong role in promoting maritime security [5].

B. ANTI-PIRACY SECURITY MEASURES

1. International Effort

The International Maritime Organization (IMO) has mandated the carriage of the Automatic Identification System (AIS) on board ships of 300 or more gross tonnage and all passenger ships [7]. The AIS broadcasts important information about a ship such as its unique ID, speed, position, heading, size, cargo, etc. [8], and greatly enhances the situational picture at the Vessel Traffic Service (VTS). VTS is a maritime traffic monitoring system that fuses data information from radar, AIS, cameras, and voice communication. The IMO has also introduced an International Ship and Port Facility Security Code (ISPS Code) to create security requirements for vessels and port facilities [5].

2. Regional Effort

In the region, the International Maritime Organization and the littoral states have introduced a mandatory ship reporting scheme for the Malacca and Singapore Straits known as STRAITREP, which facilitates and enhances identification and communication between ships and shore-based authorities [9]. Many security measures have also been introduced by the Maritime Port Authority, such as restricted access to waters surrounding high-value installations, screening of containers, and enhancing of security at sea-entry checkpoints. Other measures include face-to-face checks for crew and an increased presence of patrol craft. The selective escort of sensitive vessels in the port waters and Singapore Straits is carried out by Sea Security Teams (ASSeT) [6]. To improve surveillance coverage, the littoral states have also installed several new radars, such as the Surface Picture Surveillance System (SURPIC) for the Singapore Strait, by Singapore and Indonesia [10]; new radars at Changi Naval Base, by Singapore [11]; and the Marine Electronic Highway (MEH) along the Malacca Strait, by Malaysia [12].

C. MARITIME INTERDICTION

1. Surveillance and Data Fusion

In maritime interdiction, a distinction must be made between the operational nature of “surveillance” and “physical presence” [2]. Most of the measures that have been introduced fall under the “surveillance” category. Systems such as SURPIC, MEH, and AIS mainly improve situation awareness coverage which is important for decision-making. Boyd writes that there is a need for improvement in sensor and communication coverage, faster processing power, better display devices, and good fusion facilities [13]. With so many surveillance systems in place churning out loads of contact data, it is desirable to fuse these heterogeneous sources to form a composite situational display. A fused situational picture will facilitate a more effective decision-making process. Data fusion of different radar systems is a well-studied area [21, 22], and the fusion of radar and electro-optic sensors has also been demonstrated [23]. Data fusion of AIS and radar has been demonstrated by Dalian Maritime University [24]. Information from the above mentioned surveillance system, together with the detection from communication (COMINT) and electronics intelligence (ELINT), as well as high-level reports from sources such as patrol craft and neutral shipping, can be used to infer information and even the intentions of the contact (hostile, friendly, neutral, or unknown) with the use of multi-agent systems [25].

2. Physical Presence

The other aspect, which is physical presence, is also very important. Physical presence can be enhanced by conducting ship and aircraft patrols. Physical presence is good for deterrence and interdiction purposes, including close-range observation and even boarding of a suspicious ship. Physical presence will also allow fast response for search and rescue operations.

Examples of patrols include the coordinated naval patrols conducted by Malaysia, Indonesia, and Singapore (Operation MALSINDO), which were implemented in July 2004, and “Eye in the Sky” [2].

3. Roles

Surveillance is the responsibility of the Maritime Port Authority, whose main role is to manage vessel traffic to ensure navigational safety and port/maritime security [14]. The physical presence role is covered by the Police Coast Guard (PCG) and the Singapore Navy (RSN). The PCG’s role is to ensure law and order and prevent and detect crime within Singapore’s territorial waters [15], while the navy is responsible for the defense of Singapore against sea-borne threats and the protection of the sea lines of communications that encompass the Singapore Strait and its access routes [16].

4. Unmanned Surface Vessels

The Navy’s latest initiative is the evaluation of the Spartan [17] , [18] and Protector [19] unmanned surface vehicle’s (USV) ability to conduct ship inspection and to protect the anchorage. Each USV is equipped with video camera, radar, and communication systems to provide live-feed video images back to the base. However, the unmanned system has its own limitations, such as the absence of a ship-boarding capability. After the positive identification of a suspicious target, manned patrol craft (PC) must still be deployed to board the suspicious vessel for the interception task. Throughout this thesis, the manned patrol craft and unmanned surface vessels are termed “interdiction resources.”

D. DECISION MAKERS’ COGNITIVE CHALLENGES

With up to a thousand ships in the Singapore Strait at any one time and sixty high-speed passenger ferries plying the waters between Singapore and the Indonesian islands every day, cutting across the busy shipping lanes of the Strait [1], it is a challenging task for an operator to track the intentions of every ship. Even with a composite situational picture, it is still a tedious task for an operator to evaluate the thousands of contacts displayed on the Vessel Traffic System (VTS). The challenge is further increased during a decision-making process to determine which patrol craft or USV should investigate which contact.

The decision maker's ability to think may be affected by confusion, overwhelmed senses, debilitation, or paralysis [20]. The quality of the decision may be affected by cognitive tunnel vision in which the decision maker's attention is distracted due to cognitive overload. As a result, the decision-making process may be biased. The quality of the decision may also be affected by information overload if the decision maker is unable to establish situation awareness because of inaccurate, missing, or ambiguous data in a cluttered environment. In addition to hardware influences, Boyd [13] writes, "the implicit nature of human beings" should also be emphasized. Difficulties in the contact evaluation process may prevent the effective deployment of the interdiction resources. Boyd emphasizes that, to make a sound decision, there is a need for insight and vision "to unveil an adversary's plans and actions, as well as foresee one's own goals and appropriate plans and actions."

E. PLAN GENERATION OBJECTIVES FOR MARITIME INTERDICTION

Given the high density of shipping traffic in the Singapore straits, the coordination and tasking of USVs and PCs to ensure security in the straits will be a laborious task and cognitively challenging. The main objective of a plan-generation decision support system in maritime interdiction is optimal deployment of interdiction platforms to investigate shipping traffics.

The first research question that this thesis will address is whether a conceptual blending theory [26] can be used to model Boyd's OODA mental process [13] to generate plans for maritime interdiction. The second research question is whether the bio-inspired operator "ticket" can be used to deduce a contact's course-of-action [27]. Finally, the third research question is whether software blending that is implemented using the Compounded Multi-Agent System (CMAS) library [27] can be used to support real-time plan generation.

The plan generation process has two sub-objectives: contact course-of-action (CCOA) analysis and Interdiction resources course-of-action development (ICOA). The first objective of the plan generation process is to determine if the contact course-of-action model can be derived from the composite situation picture through “focus and direction” [13]. Then, each contact can be prioritized according to its inferred attributes, such as attack probability and time criticalness.

The second objective of the plan generation system is to be able to deploy interdiction resources to a high-priority threat so as to maximize effectiveness. Each interdiction will have different capabilities. For example, a manned patrol craft will have police officers on board who are able to perform the boarding tasks required to halt a ship. However, an unmanned surface vessel is better for close-in investigation of suspicious craft. Thus, the capabilities of the craft selected for an interdiction must match the particular characteristics of the suspected threat.

F. THESIS SCOPE

The scope of the thesis is to model the Boyd’s OODA mental process [23] using the conceptual blending theory [26] to develop course-of-action for maritime interdiction resources. The conceptual blending theory will be implemented using the NPS CMAS Library [27]. A multi-agent system will be used to model the human expert in the process of the threat course-of-action identification. The threat assessment model is based on Surface Warfare Threat Assessment [28]. It is assumed that a composite situational picture will be available for the plan generation process. The contact course-of-action will be inferred from both low- and high-level data. The low-level data will include Kinematics and ship attributes available from radar, the AIS system, and intelligence systems, while the high-level data will include spot reports from a neutral shipping or video system. A Simkit-based simulator was built on top of the simulator developed for the NPS SEA Integrated Project for Port Security Strategy 2012 [29]. The purpose of the simulator is to assess the usefulness of the plan generation system. Though the interception process is modeled, the minor details of the boarding process, such as fire exchange, boarding, shipboard search, and the rescue process is not explicitly modeled. As this is a proof-of-concept demonstrator, the attributes used in the plan generation process may not be exhaustive.

G. MOTIVATION

The plan generation process was inspired by the NPS SEA Integrated Project for Port Security Strategy 2012 [29]. The Port Security Strategy proposes a conceptual system of systems to improve port security measures. The scenario includes a combination of static and mobile sensors to provide surveillance coverage for the port of Oakland. Mobile resources, such as unmanned surface vessels and patrol craft were scripted in fixed patrol routes, which are not optimized. It would be better if a plan generator were available to manage the maritime interdiction resource deployment. The simulator used for the study was enhanced to incorporate features required for the plan generation process.

This thesis was also inspired by Tan's Master's thesis on the MAS Intent identification System [25]. Tan demonstrated the use of a conceptual blending theory and the MAS concept to infer the intention of each track, classified as Hostile, Neutral, Friendly, and Unknown. The MAS is also able to detect swarm-like coordinated strikes.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE SURVEY

A. INTRODUCTION

Within the context of this thesis, the relevant theories are the following: conceptual blending theory, software blending mechanism, Boyd's observation-orientation-decision-action (OODA) loop theory, Probability Estimates of Events, Threat Assessment model, Inducting Reasoning, Recognition Primed Decision Making and Discrete Event Simulation & Simkit. The relevant work done in plan generation is also briefly described. Some related work, which are described in details, are the Commander Model in Joint Warfare System; the Course-of-Action Analysis (COAA) Concept Exploration effort by DARPA; the Course-of-Action Simulation Analysis by Ohio State University; the Recognition Primed Decision Agent; the Operational-Level Naval Planning Using Agent-Based Simulation at NPS; and the Air and Surface Threat Assessment at NPS.

B. THEORY

1. Conceptual Blending Theory (CBT)

The Conceptual Blending Theory developed by Coulson [30] and Fauconnier and Turner [26], describes the way humans process and rationalize information through a set of mental operations. In their book, Fauconnier and Turner present various examples that show how the theory of conceptual blending is one possible explanation of the way humans think. The theory also explains the process by which humans assign meaning to incoming information from sensory input, integrate it, and thus learn and gain knowledge.

Conceptual blending is a set of operations in which mental spaces are integrated to form new mental spaces. Mental spaces are small conceptual packets, interconnected in the working memory, that are constructed when humans think and talk. Within the mental spaces are elements of knowledge that are structured by long-term schematic frames called "organizing frames," which shape or govern the elements in the mental space. The mental spaces are interconnected and modified as thoughts and discourse unfolds. For example, in shipping traffic contact analysis, each of the shipping traffic's intentions, in terms of attack probability and attack tactics, against each high-value unit present can be derived by using the predator-prey frame during the process of constructing the hypothesis blend. The predator-prey frame suggests that there are several ways that a predator can attack a particular prey. Similarly, there are various ways that a terrorist ship can attack a high-value unit. The attack probability of each tactic can be modeled by using a multi-agent system.

Fauconnier and Turner [26] suggest that humans are unconsciously, constantly blending when they are talking, listening, and imagining, in every aspect of human life. The blending process happens at fast speed and is able to generate many blends in parallel. The blended space can, in turn, serve as input space for subsequent blends, as shown in Figure 1.

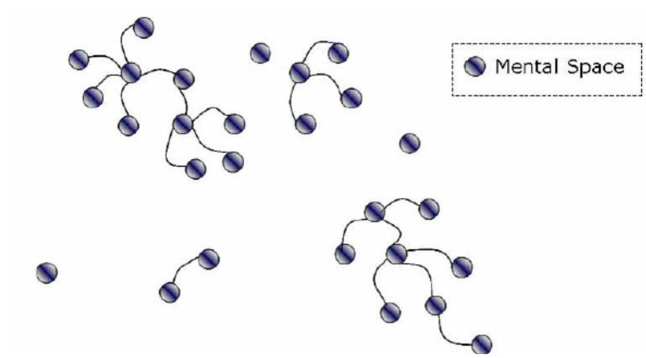


Figure 1. Complex Integration Network (From [31])

A simple integration network is shown in Figure 2. There are two input spaces connected by solid lines that represent cross-mapping among related elements in both input spaces through "vital relationship." The generic mental space contains the rules for the blending process and guides it by selectively projecting the elements from the input spaces into the blended space as shown by the dotted lines. The blended space contains the newly projected elements and an emergent structure represented by the solid square in the blended space. The links between the mental input spaces are known as "outer-space" links and are compressed into an "inner-space" link inside the blend. The blend is generated through:

a. Composition of projected elements from the input spaces. For example, each of the hypothesis blends is composed of one contact, one high-value unit, and one attack tactic.

b. Completion is based on independently recruited frames and scenarios. For example, with the attributes of the contact and high-value unit, the attack tactic is computed for its attack probability based on past experiences which represent the recruited frames and scenarios.

c. Elaboration through mental simulations is based on the new organizing frame. This is known as "running the blend" that models the process of a human being anticipating results or consequences by thinking or imagining into the future. In the maritime terrorist example, after composition and completion, the process of elaboration will compute the time that the contact might strike.

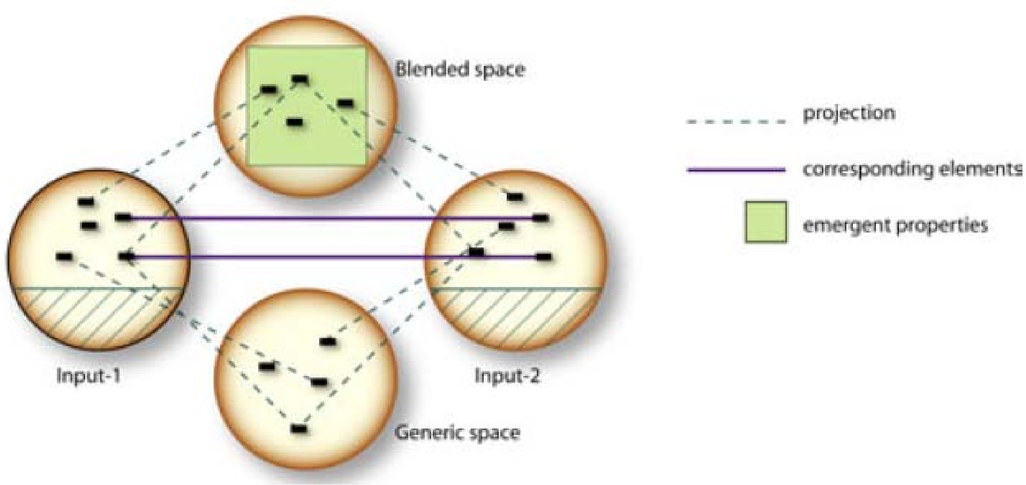


Figure 2. Simple Integration Network (From [27])

After the blending process has ended, the projected or simulated counter-factual conclusion that resulted from the elaboration process can be back-projected into the input space to add meaning and understanding to the input spaces. For example, after the elaboration process, the tactic hypothesis blend with the highest attack probability can be back-projected into the contact input space to indicate the level-of-attack probability of the contact.

Similarly, the elaboration process can also back-project vulnerability to the high-value-unit input space to indicate its vulnerability to terrorist attack.

In addition to the elements composed from the input spaces, the newly blended space compressed the vital relationship between the input spaces, known as the outer-space link, into the inner-space link in the blended space. Fauconnier and Turner claim that it is this compression ability that allows a human being to gain “global” insight and human-scale understanding” [26, ch. 16]. The term “compression” in cognitive science refers to “transforming diffuse and distended conceptual structures that are less congenial to human understanding so that they become more congenial to human understanding, better suited to our human-scale ways of thinking.” The resultant compressed inner link can then be uncompressed anywhere in the blending network in order to access the mental spaces associated in the blended space. Some of the vital links identified are Change, Cause–Effect, Time, Space, Identity, Change, Uniqueness, Part–Whole, Representation, Role, Analogy, Disanalogy, Property, Similarity, Category, and Intentionality [26, p. 101].

There are four types of blending networks. In a simple blending network, the cross-mappings between input spaces are usually a frame to values connection. The relevant part of the frame in one input is projected with its roles, and the elements are projected from the other input as values of those roles in the blend. For example, when blending a high-value-unit input space and a terrorist input space, the generic space seeded with the high-value-unit input space and an attack tactic looks for a predator that will form a relationship with the high-value unit using that attack tactic.

A mirror network is an integration network in which all spaces (inputs, generic, and blend) share an organizing frame. For example, during the elaboration process, when both the threat and the high-value unit are simulated in the same area of operation with the same environment, both are projected to the same organizing frame. This is necessary in order to derive all the information, such as position of collision, time to collision, and distance to collision.

In a single scope network, there are at least two input spaces, each with a different organizing frame. One of the organizing frames from one of the input spaces is projected to organize the blend. The organizing frame of the blend is an extension of the organizing frame of one of the input spaces, but not the other. Fauconnier and Turner use the illustration of a company's chief executive officer (CEO) "fighting" with another company's CEO. The illustration blends the business context with the sport of boxing. The frame that is being projected is from the business input space instead of the boxing input space since it is a business, not a sport competition that is taking place. In a double scope blend, where both inputs have different organizing frames, the blended space's organizing frame is made up of parts of each of those frames and has an emergent structure of its own; that is, a new type of organizing frame is created by the double-scope blend. Fauconnier and Turner cite the illustration of a computer desktop, which is a combination of computer frame and an office desktop frame.

2. Software Blending Using a Multi-Agent System

Professor J.E. Hiles [27], [32] demonstrated the Conceptual Blending Theory using software blending in Project IAGO, using multi-agent coordination techniques motivated by the biochemistry of biological cells. The software blending was implemented using multi-agent systems that coordinate activities using three-key bio-inspired operators called Membrane, Connector, and Ticket.

The membrane is the common environment within which all the related mental spaces such as generic space, input space, and blended space exist. For example, the contact, high-value unit, interdiction resources, and all resultant blended spaces are projected into the same membrane.

Connectors that resemble the receptors and control in biological cells are used to connect one space to another. There are two types of connectors: stimulus and response. Stimulus connectors are used by mental spaces to project some of their elements into the membrane. Response connectors are "query-like" operators that request elements from the membrane. For example, when a contact input space is projected into the membrane, knowledge elements (e.g., a sensed state) that are ready for further processing are extended as stimulus connectors. The generic space for forming hypotheses will extend response connectors to look for new contacts with sensed-state equals to an unknown or hostile state.

Tickets contain the procedural information for agents. Each ticket contains several frames with each frame having individual receptors either extended or retracted, depending on the state in each frame. Each frame can be in either an active or a dormant state. There are two types of tickets: data or operational. Data tickets are used to gather information from the "world outside the ticket," while an operation ticket contains the sequence of operation. The sequence of operation of corresponding tickets will be executed when two connectors match. The connections formed are persistence and scale-free, which can then be used to built the blending network. Examples of data tickets include many reactive agents for contact, high-value-unit and interdiction-resources input spaces, for monitoring the real world environment and updating states in the membrane. An example of an operational ticket is the contact course-of-action hypothesis ticket in which each frame represents one cue that a human operator uses in threat assessment.

Project IAGO has successfully applied computational models to anticipate asymmetric threat operations. The project used the notion of a compounded multi-agent system (Figure 3) in which multi-agent were used to represent the mental spaces within agents having the cognitive capability to produce "bottom-up" knowledge structures grown through the process of conceptual blending. One of IAGO's important approaches has been to focus on the perspective of a subject instead of on the observer's point of view. It used a perceptual filter to analyze a series of complex events by applying meaning to key incoming events so to construct meaning for the subject. For example, if a series of events in an maritime threat scenario indicate that "Threat is inside near range" + "Threat is approaching" + "Threat is a small ship" + "Threat contains small crew size" + "Threat is heavily laden" + "Threat is moving fast," a "suicide bombing" ticket will generate a higher probability than a "neutral ticket." The key mechanism used for such a complex event analysis is the ticket, which is capable of continuous adjustments based on incoming event variations and goal orientation.

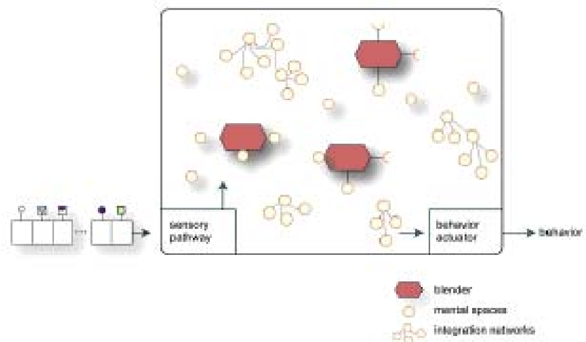


Figure 3. Compounded Multi-agent System.

3. Boyd's OODA Loop Theory

Boyd's OODA (Observation-Orientation-Decision-Action) loop is a theory of knowledge formation [13]. The OODA loop describes how humans construct mental models of their environment both through immediate observation and orientation and under the influence of experience, culture, history, genetics, etc. These mental models are then used to decide on a course-of-action. The outcomes of the decision are known through subsequent observation. The OODA is depicted in Figure 4. Observation is the information collected about the enemy and the environment. Orientation is the analysis of the information collected. Decision is the selection of a course-of-action from the alternatives. Action is the implementation of the course-of-action selected.

A simple cause and effect analysis is ineffective mainly because of the nature of the dynamics and the ill-structured and ill-defined characteristics of the problem space. The efficacy of the OODA loop is attributed mainly to its ability to overcome the problems of friction, limited time, and enemy action. Friction introduces non-rational outcomes which cannot be anticipated and is impacted by several unknowable variables in any plan or action. Limited time restricts the ability to collect and digest information. Enemy action refers to the fact that the enemy is constantly adapting and changing its course-of-action based on its adversary's course-of-action. The OODA loop occurs continuously. After the action process, the observation process starts immediately, with new information constantly collected, analyzed, and used for subsequent processes.

Boyd writes that orientation represents images, views, and impressions of the world that are shaped by genetic heritage, cultural tradition, previous experiences, and unfolding circumstances. It is an interactive process of many-sided implicit cross-referencing projections, empathies, correlation, and rejection. Orientation is the most important part of the OODA loop because it shapes the way one observes, decides, and acts as well as the ability or inability to conduct many-sided implicit cross-referencing.

This thesis uses conceptual blending theory to describe the OODA process. The observation process is implemented using reactive agents. The orientation process is implemented using operational ticket agents. The decision is implemented through the analysis of counter-contact course-of-action goals and the forming of own course-of-action alternatives. Then, linear assignment is used to choose the course-of-action among the alternatives.

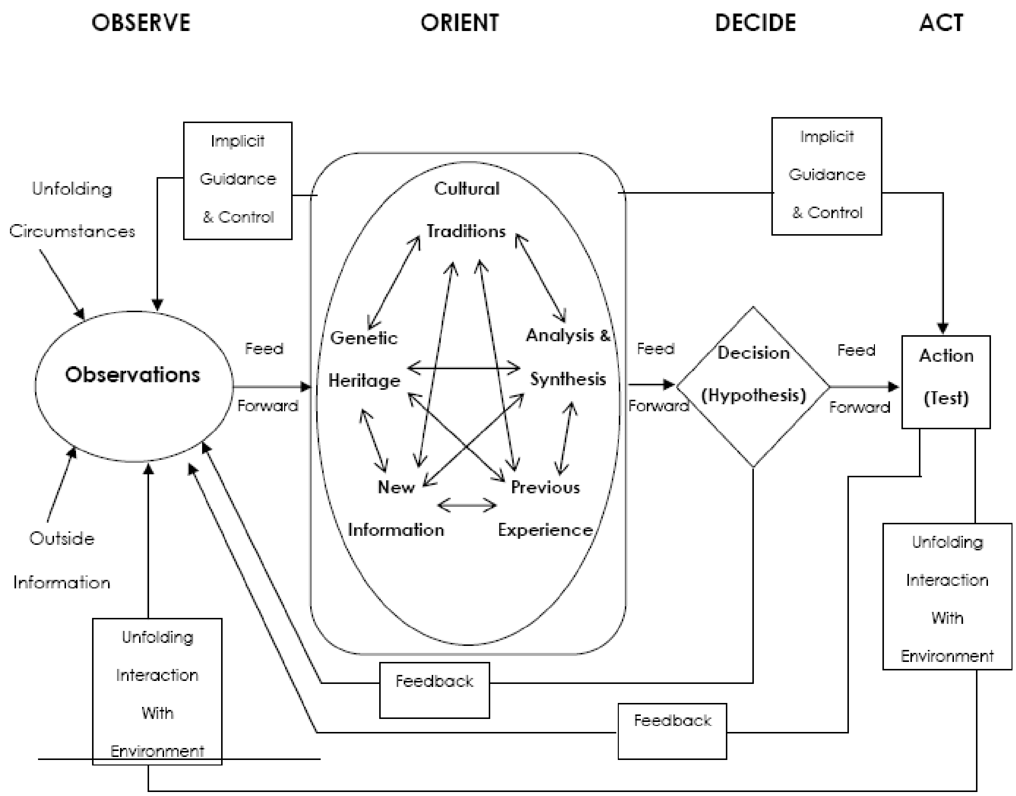


Figure 4. OODA Loop taken (From [13].)

4. Military Decision-Making Using Probability Estimates of Events

Military decision-making often involves a process using probability estimates of events to choose between different course-of-actions in battle [20]. Reeves [20, Table 1] uses five general characteristics to characterize an environment of extreme information ambiguity: friction, ambiguity, time pressure, delayed action-feedback loops, and high stakes. Friction can be caused by external factors such as enemy action or an adverse environmental condition. It can also be caused by internal conflicts because of management and technology challenges, or the complexity of the task. Ambiguity can be caused by a discrepancy in the data, the coverage of the rules of engagement, or the commander's intent. Time pressure is mainly caused by a lack of information when a decision must be made. Delayed action-feedback loops and high stakes are self-explanatory.

In a maritime interdiction scenario, in order to deploy maritime interdiction resources to investigate potentially suspicious ships among the busy ship traffic, probability estimates of each ship's intentions need to be established in order to prioritize the investigation process. First, several attack hypotheses are created for each contact/high-value-unit pair. Then, each hypothesis is assigned with a probability estimate to indicate its attack probability using the associated tactics. That contact is then prioritized according to the inferred attack probability for the interdiction process.

5. Threat Assessment

Liebhaber and Feher [28] investigated the threat assessment process used by experienced surface warfare personnel. Data were collected from experienced watch-standers and used to develop a surface threat assessment algorithm as part of the decision support system (DSS). The DSS can be used to support the cognitive process of surface warfare personnel operating in highly complex, fast-paced littoral environments. The DSS will help the decision maker to assess and rank contacts in order to develop appropriate a course-of-action either to reduce threat uncertainty or to neutralize the threat. The first part of their investigation was to categorize the various types of platforms into five different threat levels in littoral or open waters. Then, the following cues were used to either increase or decrease the likelihood of the threat: speed, heading, Closest Point of Approach (CPA), recent maneuvers, distance, cargo, number of vessels, sea lane, Electronics Support Measure (ESM), coordinated activity, voice communication, own support in area, destination, weapons envelope, and regional intelligence.

In this thesis, threat assessment is implemented using the operational ticket to derive a probability estimate associated with the attack tactics. Each frame will have a response connector extended to query for a cue for threat assessment. The set of cues is similar to but not exactly the same as the set used by Liebhaber and Feher because of a slight different in application context. The thesis focuses on detecting piracy and terrorist activities among the civilian shipping.

6. Bounded Rationality and Inductive Reasoning

Classical decision theory is based on instrumental rationality in which decisions take place under three conditions: certainty, risk, and uncertainty [33]. According to this theory, decisions are rational choices that are made by maximizing expected utility. This implies that all possible choices and associated probabilities with the payoff must be known in advance [34]. However, all possible choices and associated probabilities are usually not available for maritime interdiction planning, which is usually based on incomplete, inaccurate, or subjective information. Nevertheless, Arthur [35] suggests that human beings are not good at deductive logic but are rather good at pattern recognition and inductive reasoning. During the reasoning process, several hypotheses will be formed that will be strengthened, weakened, or even replaced according to input arriving from the environment.

In the course of planning and the decision-making process, human beings will attempt to conduct situational reasoning. In addition, the reasoning process usually exhibits bounded rationality, because decisions are usually made with incomplete and conflicting information [36]. This is in line with Tversky and Kahneman's study which finds that human beings do not usually make rational choices but choices that can easily be biased based on their personal experiences or preferences [37]. Simon [36] suggests that other psychological processes must then be required for decision-making. Arthur [35] proposes that an inductive reasoning approach enables human beings to deal with complications and an ill-defined problem space. Inductive reasoning can be modeled with several heterogeneous agents assigned with various hypotheses or subjective beliefs. Each agent will keep track of his own private collection-of-beliefs model, strengthening or weakening it as events unfold.

According to this theory, several hypotheses can be created for one contact. These hypotheses will be either strengthened or weakened according to cues arriving from the external environment. By assigning a different weight by which the attack probability is either increased or decreased, each cue that arrives can be interpreted independently and according to human experience. Each hypothesis, an operation-ticket agent, then autonomously adjusts its attack probability. All hypothesis tickets will have a different attack probability, updated based on experience. The overall pattern in attack probability will be able to model the human inductive reasoning process dynamically, even under rapidly changing conditions.

7. Recognition-Primed Decision Making

According to Wikipedia, Naturalistic Decision Making (NDM) as a “framework emerged as a means of studying how people actually make decisions and perform cognitively complex functions in demanding situations” [38]. Salas and Klein describe NDM as “the effort to understand and improve decision making in field settings” [39]. Both describe NDM as a descriptive theory. Both note that situations are usually characterized by stress, time pressure, uncertainty, vague goals, ambiguous information, high stakes, team and organizational constraints, dynamic conditions, and varying amounts of experience. As can be seen, NDM is different from the classical decision-making theory in which, options are usually not available.

Klein developed the Recognition-Primed Decision (RPD) model to explain how a human expert makes a decision in an emergency situation [40]. The Integrated version of the RPD model is given in Figure 5. The study described several interesting aspects of the RPD model.

In what is termed the “singular evaluation approach,” the decision maker does not compare options but evaluates them in isolation. While the comparative evaluation approach aims for optimizing the effect, the singular evaluation approach aims for “satisfying,” that is, determining whether the first option that comes to mind satisfies the requirements of that particular circumstance. Optimizing is usually difficult while satisfying is more efficient.

Each option is evaluated through a process of mental simulation to identify flaws in the decision. If there is no problem, the option is executed; otherwise, the next option is evaluated. The decision-making process is fast, less than one minute. There are three variations in the decision-making process:

- The situation is recognized as typical and familiar. In this variation, the decision-maker is clear about the goal, cues, expectancy, and action.
- The situation is atypical. A remedy procedure such as seeking for more information or story-telling is required to understand the situation.
- The course-of-action contains flaws, which can be identified through mental simulation.

In this thesis, recognition of a typical situation can be implemented using the operation ticket agent to monitor all relevant cues to identify a typical situation. A typical situation is a contact course-of-action, with cues drawn from the composite situational picture. The expectancies in this situation will be based on the course-of-action hypothesis. The action taken in the course-of-action is the deployment of interdiction resources. So far, the process only addresses the first variation. The second variation is one that lacks information about a suspicious craft. In this situation, an unmanned surface vessel is deployed to gather more information before deploying police coast guards to board the craft. The third variation is one in which none of the interdiction resources are able to counter the contact in time. In this circumstance, an external agency such as a helicopter might be deployed.

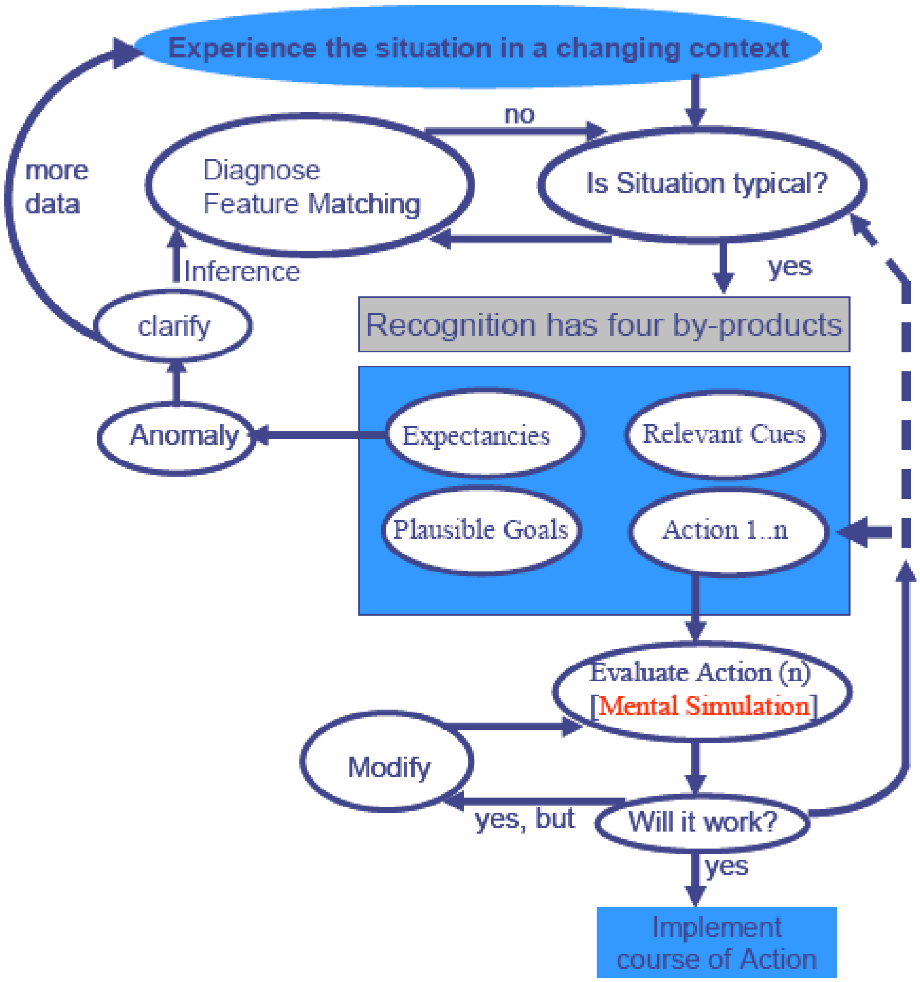


Figure 5. Integrated Version of the Recognition-primed Decision-making Model (From [41]

8. Discrete Event Simulation and Simkit

The event-based simulator developed for this thesis to test the plan generation demonstrator was based on the event graph paradigm [49], [50], [51] and can be built based on a suite of Java library call Simkit [52]. The LEGOS framework [53] can be used to organize a large-scale simulator into several smaller components for easy development. The Discrete Event paradigm and the Simkit library have made provisions for the sensing and movement models found in [54].

C. RELATED WORK

1. Commander Model in the Joint Warfare System (JWARS)

In the Joint Warfare System (JWARS), the Commander Model (CM) is used to perform situation assessment and course-of-action (COA) selection, while the Commander Behavior Model (CBM) is used to bias decisions in keeping with a commander's leadership style [48]. The CM is a hybrid artificial intelligence system that models doctrine with fuzzy rule sets, together with a tree-based lookahead algorithm for the strategy. The CBM employs behavior-based fuzzy rule sets to augment the CM in assessing the situation, and in biasing the COA selection criteria. The CBM extends from the Myers-Briggs personality traits to link personality traits to military attitudes, consequences, and values. The resulting sets of values are combined to select a specific course-of-action with an auditable trail using fuzzy rule sets. The CM/CBM is applicable to decisions from multiple echelons.

2. U.S. Defense Advanced Research Projects Agency's (DARPA) Course-of-Action Analysis (COAA) and Concept Exploration Effort

The U.S. Army uses the Military Decision-Making Process (MDMP) described in Field Manual 101-5, Staff Organization and Operations, to prepare for a combat operation [49]. The decision-making process is a specialization of the general decision-making process: understanding the problem, proposing alternatives, analyzing each alternative, comparing them, and selecting one to execute. These processes can be summarized as: mission analysis, course-of-action (COA) development, and COA analysis. Mission analysis involves the gathering, reviewing, and understanding of information about a given mission: the enemy, troops, terrain and time available. Course-of-action development produces three to five feasible, acceptable, suitable, distinguishable, and complete course-of-actions. COA analysis is done to gain a deeper understanding of the consequence, and to improve the course-of-action's structure through war-gaming. The course-of-actions are evaluated against a set of commander's evaluation criteria through the formulation of COA analysis as a Constraint Satisfaction Problem.

3. Course-of-Action Simulation Analysis (CASA)

Scientists at Ohio State University performed a course-of-action simulation analysis for the U.S. Army [50]. Hanna et al., emphasize that future U.S. military planning processes will “depend upon analysis systems to anticipate and respond in real-time to a dynamically changing battle space with counteractions.” Their research areas include: building a simulation test bed, a scalable, flexible simulation framework, automated scenario generation techniques with dynamic updating, intelligent adversarial behavior modeling, effects-based/attrition-based behavior modeling, and real-time analysis for comparing and grading the effectiveness of alternative simulations. They emphasize that modeling and simulation (M&S) technologies can assist the planning and decision-making chain with COA development and COA effectiveness prediction.

Course-of-action simulation analysis covers a large number of course-of-actions, ranks them based on suitability and predicted results, and then down selects to the preferred approach. Genetic algorithms were used to create a large number of COA permutations from subject-matter-expert-defined initial conditions and constraints. The large set of course-of-actions is then reduced to a set of pareto-optimal course-of-actions containing unique COA characteristics. The authors also point out that “the best COA may not be the one with the highest score. Rather, a COA that scores high against many eCOAs rather than a highest score against an expected eCOA may be the more prudent choice.”

4. Recognition-Primed Decision Agent (RPDAgent) [38]

The recognition-primed decision agent was developed based on Klein’s recognition-primed decision (RPD) making concepts to model a military decision-maker at the operational level of warfare [51]. A person’s decision-making ability depends on his ability to recognize a particular decision situation and to identify an appropriate action based on past experience. Sokolowski uses the frame data structure that corresponds to a single experience that holds the cues, goals, and actions that describe that experience. In each decision situation, the RPDAgent searches its table of frames to look for a match. If a match is found, the matching frame, together with its associated cues, goals, and actions will be retrieved. Otherwise, the model will ignore the situation. Upon recognizing a matching frame, the RPDAgent develops an internal representation of the decision situation, similar to the way humans develop an internal interpretation of their external environment based on experience.

Environmental variables that describe the decision situation's external environment are aggregated into cues, which are higher-level abstractions, to represent its internal interpretation of lower-level environmental variables that describe physical or mental parameters. Examples of location cues are beach topography, beach hydrography, water obstruction, staging area, etc. Examples of environmental variables for the beach topography are steepness, sand type, and obstacles. The environmental variables are assigned numeric values. The cue value is calculated by summing up the associated environmental variables and then converted into a fuzzy set, of which the shape and range define experience within the RPDAgent. One Decision Agent is provided for each active decision that uses the internal representation of the situation and encoded experience to choose the potential decision that appears most favorable [52]. Each action represents either a past or a current decision option that is characterized by environmental variables. The satisfaction of an action is computed by summing the cue values for each action. The action with the largest action value is considered the most favorable. It is also converted into a fuzzy value to serve as an intuitive indicator of the most favorable action.

The Decision Agent subsequently instantiates one Reactive Agent for each goal under consideration [52]. The most favorable action is processed to determine how well it meets the goals of the situation based on experience. This is analogous to running mental simulation to determine if the selected action satisfies the current situation. A set of cues are used as indicators of the satisfactory of a goal. Goals are also associated with fuzzy sets that define how well a goal is being satisfied. If one or more goals are unsatisfactory, a negotiation process is carried out to derive a compromise.

The reactive agent for each goal will try to negotiate a compromise by lowering the standards of its goals. Negotiation is implemented by mapping the previously calculated goal value to a revised goal value through a multiplication factor that represents the tolerance of the risk. Subsequently, a compromise is reached if all goal values are satisfactory. If all goals are satisfied, the action under evaluation is selected. Otherwise, negotiation is carried out for the next most favorable action. If no satisfactory action can be found, a default decision is selected.

5. Operational-Level Naval Planning Using Agent-Based Simulation

In his thesis, Ercetin [53] noted that a plan must have the following characteristics: relevance, clarity, timeliness, flexibility, participation, economy of resources, security, and coordination. The planning process is depicted in Figure 6. In a commander's estimate, the decision maker analyzes the situation, evaluates the threat, and perceives the mission. The subordinate commanders prepare a detailed plan including such aspects as allocation, deployment, and employment of forces in the operational areas.

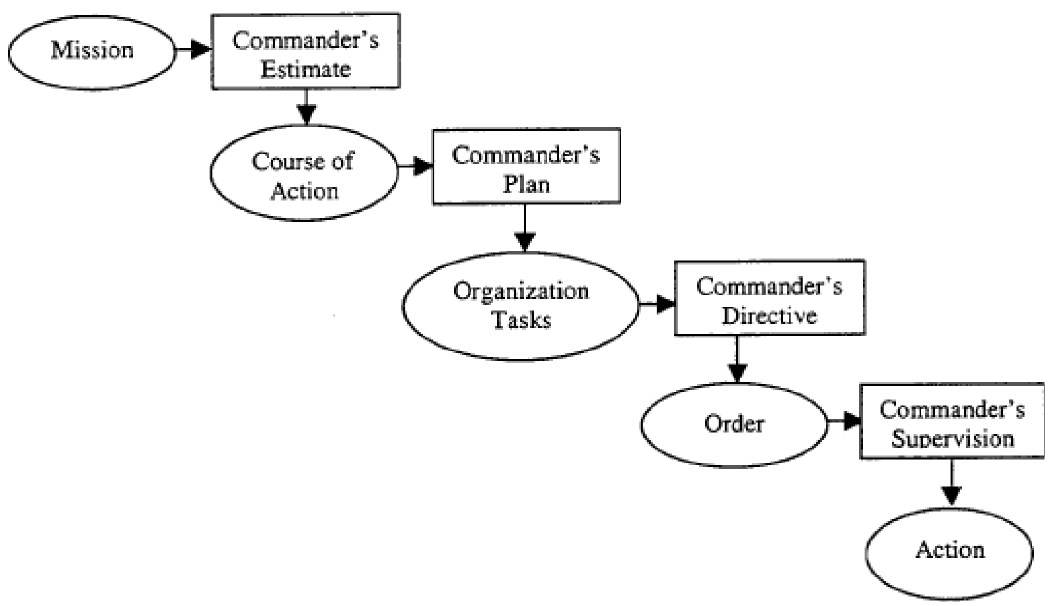


Figure 4. Military Planning Logic (NDP 5, 1996)

Figure 6. Military Planning Logic (From [47])

Ercetin mentions two broad categories of planning: force planning and operational planning. Force planning is done to build up capabilities, while operation planning is the allocation and movement of forces. His thesis focuses on operational planning. In the thesis, commander agents were used for force allocation, force deployment, and force movement. The commander was characterized by ten attributes: intelligence capability, speed preference, staying power preference, surface platform usage tendency, sub-surface platform usage tendency, air platform usage tendency, aggressiveness, budget, platforms, and attribute considerations. He named three goal types: allocation, deployment, and movement; and seven allocation goals for seven types of ships, three deployment goals for three different theatres, and two movement goals for stay or transit.

6. Air and Surface Threat Assessment

In his thesis, Ozkan [31] implements a threat assessment model, using a multi-agent system and conceptual blending theory, to mimic how a human expert assesses the intention of an incoming air threat. The thesis shows that a multi-agent system and conceptual blending theory can be used to introduce cognitive intelligence into a computational model. In another thesis, Tan [25] also implements threat assessment for surface warfare based on such cues as platform type, position, flag, destination, heading, speed, communication, activity, origin, and ESM to establish various forms of violations. The violations are: the security zone, area to be avoided, speed threshold, speed violation, location, and traffic heading. The violations are used to determine the track's intention through a weighting strategy in terms of "friendly," "neutral," "potentially hostile," or "unknown." The results have been quite well received by the naval officers surveyed.

D. CONCLUSION

Although considerable work has been done in the area of plan generation, none has been done using conceptual blending theory (CBT). Software blending can be implemented using the suite of bio-inspired operators available in the CMAS library. The human-expert mental process can be modeled using Boyd's OODA loop theory, while Klein's recognition-primed decision approach can be used to model the myriad details in the OODA mental process. The probability of each attack tactic can be modeled using probability estimates, updated through a process of threat assessment and inductive reasoning. Finally, discrete event simulation and Simkit can be used to implement a simulator to demonstrate the utility of the plan generator.

III. DESIGN OF A PLAN GENERATOR FOR MARITIME INTERDICTION

A. INTRODUCTION

The previous chapter described the theories on which the design of a plan generator for maritime interdiction might be based. Given the work done in the area of plan generation already described, plan generation is a heavily researched area for either providing decision support tools to aid human beings or to enhance the artificial intelligence of a non-player character in computer games or simulation systems. Nevertheless, plan generation using a conceptual blending theory is a novel application that is based on the way experienced operators rationalize a situational picture and course-of-actions are developed. This chapter will describe the design of a plan generator based on conceptual blending theory and the process of hypothesis generation, goal analysis, course-of-action formulation, analysis, and selection.

B. MENTAL PROCESS

The mental processes of observing a composite situational display, deriving a contact course-of-action hypothesis, and evaluating and selecting a course-of-action can be based on Boyd's OODA cycle [13]. The objective of each of the mental processes that a surface warfare operator might use to plan for maritime interdiction is summarized in Table 1.

Observation	To collect data concerning all contacts, High Value Units and Interdiction Resources
Orientation	To infer course-of-action for each contact
Decision	To analyze the required Goal to counter the contact course-of-action To develop all possible course-of-actions that satisfy the goals identified To evaluate and choose a set of course-of-actions.
Action	To monitor the development of the situation during decision execution.

Table 1. Objective in Each Mental Process

1. Observation

The operator observes each of the contacts displayed in the situational display. The display can be a fusion of a radar plot with other sensory sources such as the Automatic Shipboard Identification System, electronics intelligence, and other spot reports. Essentially, the four kinds of information available for further processing are kinematics and descriptive information (Table 2), intelligence information (Table 3), and visual observation (Table 4).

Data element	States	Description
MMSI number	Unique ID	unique reference identification
Navigation status	At anchor Underway Not under command	
Position	x and y	Cartesian coordinate system in x and y
Heading	0 – 360deg	The heading of the contact
Speed	0 – 50knots	Travel speed of the contact
Origin	Indonesia Malaysia SLOC	A contact can be coming from the southern Indonesia island, northern Malaysia peninsula, or the sea lines of communication.
Craft Size	Small Big	This is the size of the contact. Small refers to small craft such as pleasure craft, tug boats, and fishing vessels. Big refers to large container and tanker ships
Sensed State	Unknown Neutral Inferred Neutral Inferred Hostile Hostile	A particular contact can be in either one of these five states. The states represent the human's understanding of the contact based on a spot report or investigation by the patrol craft.

Data element	States	Description
Engagement State	Not Engaged In Process Neutralized	This state indicates the engagement status of a contact. It can be not engaged, currently in the process of being engaged, or have been neutralized.

Table 2. Contact Kinematics and Descriptive Information

Data element	States	Description
AIS Error	True / false	This element indicate whether there has been an Automatic Identification System error associated with the contact,
Electronics Intelligence	Neutral / Potential Hostile	This state is based on the transmission coming from the shipboard radar or fire control radar. Each ship should have a unique radar transmission signature.
Communication Intelligence	Neutral / Potential Hostile	This state is based on the interception of radio conversation of a contact ship with another party. The states are either suspicious or not suspicious.
Communication Procedure	Suspicious Normal	This state is based on a suspicious conversation with the contact.

Table 3. Contact Intelligence Information

Data element	States	Description
Crew Size	Normal Too few Too many	This state represents the crew size either observable or reported on board the contact.
Crew Behavior	Normal Abnormal	The behavior of the crew can be either normal or abnormal.
Small Arms Sighted	True / false	This aspect indicates whether small arms such as knifes or pistol have been sighted onboard the contact

Data element	States	Description
RPG Sighted	True / false	This aspect indicates whether rocket-propelled grenade launchers have been sighted on board the contact.
Missile Equipment	True / false	This aspect indicates whether missile-related equipment has been sighted on board the contact. Examples are: electro-optics sensors or fire control radar that can be used to guide missiles.
Missile Canisters	True / false	This aspect indicates whether missile canisters have been sighted on board the contact.
Flammable Cargo	True / false	This aspect indicates whether the contact is carrying flammable cargo.
Overloaded	True / false	This aspect indicates whether the contact is heavily laden.

Table 4. Contact Visual Information

2. Orientation

The operator uses information such as kinematics to infer a hypothesis for each contact. To identify hostile intention, contact course-of-action hypotheses can be derived for each contact against each possible high-value unit. Several hypotheses will be assigned to each contact and high-value-unit pair to represent several possible attack tactics. A “neutral intention” can be added to the list of attack tactics to compete for the likely intent. The probability of each of these attack tactics can be increased or decreased based on a set of incoming cues from the observation. This is the same method used by the expert in an air and surface warfare threat assessment [28].

The likely situation, which is represented by the contact’s course-of-action attack probability, can be “recognized” through the interpretation of the cues in the same way that an expert interprets cues to recognize a particular situation. This is similar to the recognition approach proposed by Klein [40]. However, instead of a serial recognition approach, multiple agents can be used whereby each agent processes serial recognition in parallel to improve efficiency and to reduce the complexity involved in the second variability of the RPD model [40]. The second variability suggests that when the human expert acts based on the first situation that has satisfied all conditions without comparing it with other options, it is possible that when he receives new information of new events, he will discover that the first situation has been wrongly recognized. Klein explains that the serial approach with satisfying is more efficient, while the comparative approach is more difficult, although desirable, in classical decision theory [33]. Henceforth, to derive the most probable situation, multiple agents can be introduced to process serial recognition in parallel for eventual comparison.

The attack tactics are based on the findings of Rohan [54], [55], Raymond [5], [56], and Bateman et al., [14] Six attack tactics have been identified (Table 5): suicide bombing; short-range weapon attack; boarding; suicide attack using huge container ship; suicide attack using tanker ship; and missile attack. Neutral is added to provide a possibility that the ship has a neutral intention.

S/n	Attack Tactics	Description
T1	Suicide Bombing Attack	This tactic attempts to detonate explosives on board a small craft as the small craft makes contact with the target.
T2	Short-Range Weapon Attack	This tactic attempts to launch a short-range weapon such as a rocket-propelled grenade.
T3	Boarding Attack	This tactic attempts to board the target ship.
T4	Container Ship Attack	This tactic attempts to crash a huge tanker ship into the target.
T5	Tanker Ship Attack	This tactic attempts to crash a ship that carries flammable cargo into the target.
T6	Missile Attack	This tactic attempts to launch a missile against the target.
T7	Neutral	This is not an attack tactic but represents a neutral shipping intention.

Table 5. Attack Tactics

The experience is encoded using an approach similar to the one used by Liebhaber and Feher [28]. Each of the cues is processed against each of the attack tactics by either increasing or decreasing the probability. An example of how a cue will be processed by the seven attack tactics is given in Table 6.

Cue	State	T1	T1	T3	T4	T5	T6	T7
Proximity	< 0.5nm	+++	+++	+++	+++	+++	---	---
	0.5 to 1nm	+	+++	+	+	+	---	-
	1nm to 5nm	-	+	-	-	-	++	+
	5nm to 10nm	--	--	--	--	--	+++	++
	> 10nm	---	---	---	---	---	-	+++

Table 6. Example of How Experience Can Be Coded

A survey of the interpretation of the cues with regard to the attack tickets has been conducted with several experienced naval warfare officers. The survey format is similar to that of Liebhaber and Feher [28]. However, during the first few interviews, the naval officers agreed that it is difficult to assess an individual cue in isolation. Certain cues are only meaningful when evaluated with another cue. For example, proximity and heading by itself is meaningless. A heading that is directed at a high-value unit is not threatening if it is far away. The enhanced survey format with grouping of cues is described in Appendix A. The experiences gathered are summarized in Appendix B.

Each ticket is then able to produce a probability estimate independently based on its autonomous interpretation of each cue. Such local behavior can then produce a global pattern that infers a particular attack tactic. The attack tactic can then be deduced using an inductive approach [35] through pattern recognition. The probability estimate patterns can be found in Figures 43, 44, 45, 46, 47, and 48.

Mental simulation can then be conducted for each hypothesis to simulate into the future to compute the counter-factor information of the attack. For example, with the velocity vector of both the contact and the high-value unit, we can compute into the future the possible collision time and space. This is called "running the blend" in cognitive blending theory. After the hypotheses have been established, the derived intention of the ship can be selected based on the hypothesis that carries the highest attack tactic probability. The computed attack probability becomes one of the attributes of the contact and becomes the vulnerability figure of the high-value unit. This is called "back-projection" in cognitive blending theory. The contact can now be prioritized according to its attack probability.

3. Decision

One course-of-action can be established for each interdiction facility and contact pair. Each course-of-action will then be evaluated based on the following factors:

What must be done to counter the threat?

What capability must be available to accomplish the task?

How much time do we have?

An effectiveness value for each course-of-action can then be derived. Then, a linear assignment can be done to select the optimal set of course-of-action by using attack probability as the priority and effectiveness as the cost. This approach is contradictory to Klein's suggestion in course-of-action derivation [40]. Klein found that a human expert does not use optimizing in choosing a course-of-action but bases it on a satisfying approach. This approach is efficient for a human being but is still not perfect as defined in the 3rd variability. After deciding on the first course-of-action that satisfies all conditions, the human expert may discover a flaw in the course-of-action either by mental simulation or in the midst of executing the course-of-action. The optimizing approach is used here for three reasons. First, although Klein found that optimizing is difficult for human beings, he did not imply that optimization is a bad approach for a computational model. Second, the course-of-action selection process fits a linear assignment problem frame work. The third reason is that, although Klein found that a serial approach is good for human operations, the computational model is capable of parallel processing.

After the resource-to-contact assignments have been carried out, the course-of-actions selected are then evaluated against the goals derived based on the inferred contact course-of-action. If any of the goals cannot be fulfilled for an optimal solution, an external agency such as a helicopter will be scrambled for maritime interdiction.

4. Action

After the selection of the course-of-action, the interdiction resources will be deployed. The operator will continue to monitor the situation and to amend the plan if the situation changes. Changes to the plan must be done by repeating the OOAD mental process.

C. THE CONCEPTUAL BLENDING NETWORK

This section will provide a detailed description of the mental process. The overall blending network is shown in Figure 7. The blending network starts from the top. First, the Orientation Generic Space brings together one Contact Input Space, one High-Value Unit Input Space and one Attack Tactic Input Space to form one Contact Course-of-Action Hypothesis Blended Space. Then, the attack probability for the Hypothesis Blended Space will be computed through the completion process while the time of attack will be computed through the elaboration process. Some of the blended information is then projected back to the input spaces. Second, the Goal Generic Space brings together one Contact Input space and one Goal Input space to form one Goal Blended Space. Then, the goal required will be derived through the process of completion while the time of the goal to be achieved is computed through the process of elaboration. Third, the Resource Course-of-Action Generic Space will bring together one Goal Blended Space and One Resource Input Space to form one possible Course-of-Action Blended Space. The capability matching between the goal and the resource will be determined through the process of completion while the effectiveness and time of achieving the goal will be computed through the process of elaboration. The final process involves the Decision Generic Space bringing in all possible Course-of-Action Blended Spaces and all Contact Input Spaces. It will prioritize the input space and linearly assign resources to contacts. For example, resources might refer to several number of patrol craft with different capabilities while contact might refer to suspicious ships. The detailed descriptions are provided in the sub-sections that follow.

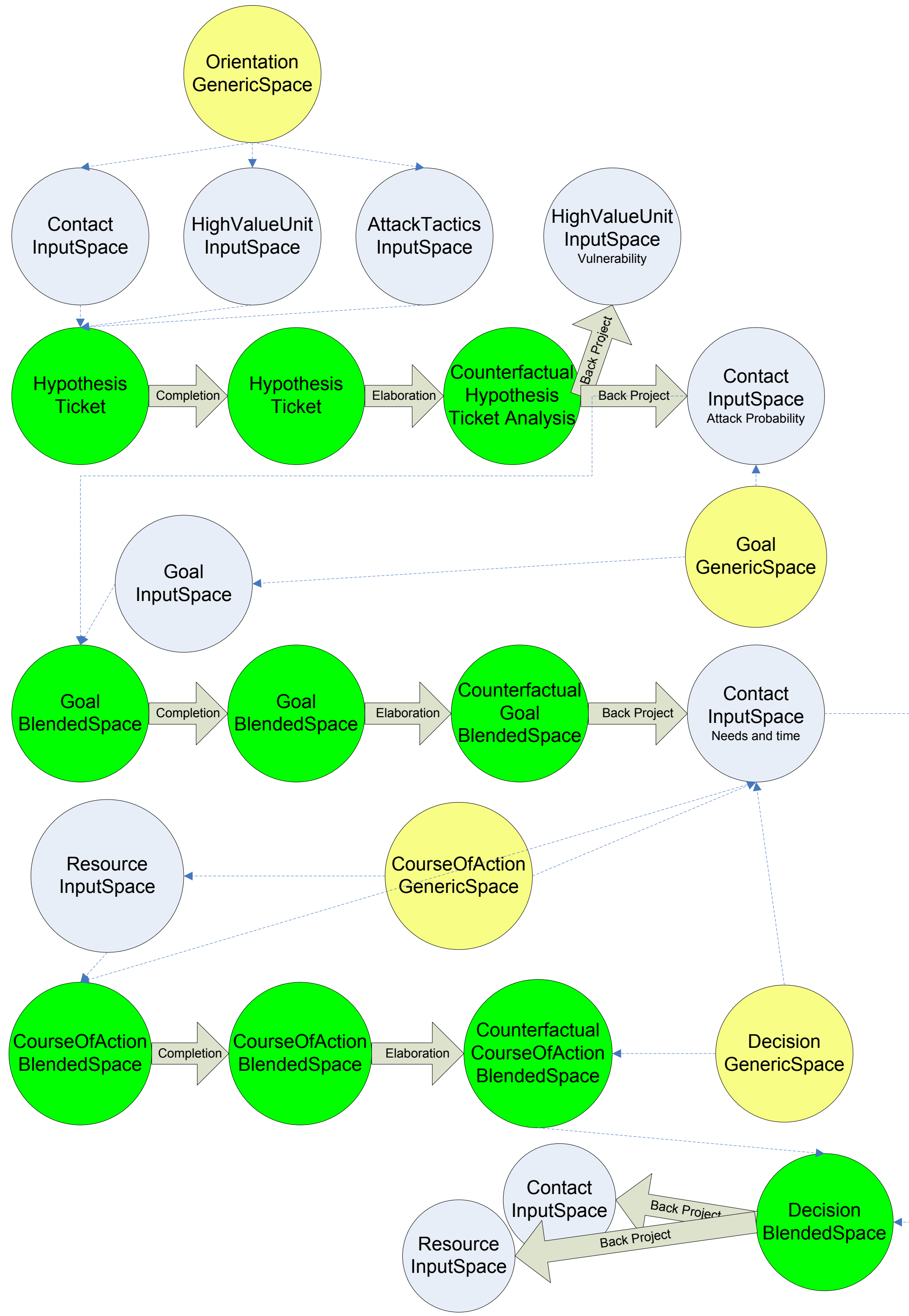


Figure 7. Overall Blending Network

1. Observation

One reactive agent is created for each contact to monitor that contact in the contact input space. The contact reactive agents do not keep any state information or process any information. They simply update each of the monitor states in accordance with the changes in the real-world environment. Agents with very simple internal states a little or no internal model of their environment are frequently referred to as “reactive agents” [27]. The contact reactive agents are created as Track Data Tickets as shown in Figure 8. The data elements are data that are translated from the real world. The lines with different shapes attached to each element are connectors that can be extended or retracted in the membrane. When a particular data element is available, the associated connector will be extended. Certain data elements will always be extended, such as track ID, sensed state, position, heading, and origin. These data elements are usually available from a maritime radar system. The other data elements may or may not be available depending on the incoming data stream from the real world. For example, the default condition of a ship is assumed not overloaded (i.e., not carrying an excessive load of cargo or fuel). However, if overloading is spotted, such a spot report will be translated by the contact data ticket and its associated connector will be extended.

Certain data elements are not available from the real-world environment but are back-projected from other mental processes. Data elements such as attack probability, possible target, time to react, and derived sensed states are counterfactual, that is, these data are not a fact yet but are mainly a result of the blending process and mental simulation. These data are described in Table 7.

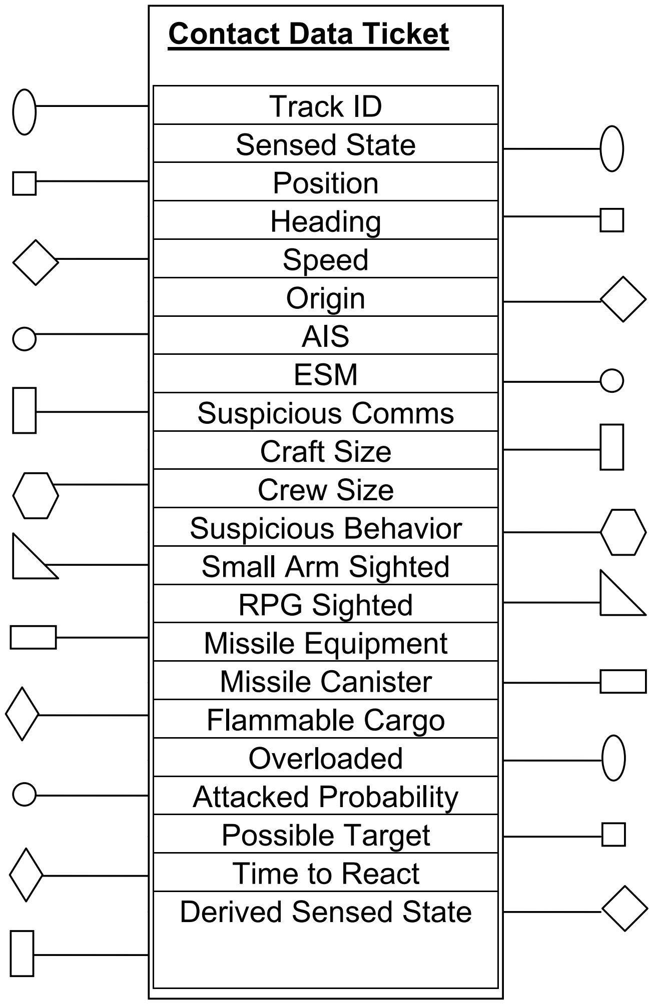


Figure 8. Contact Data Ticket (the geometric shapes extending from the ticket represent a variety of connectors)

Data element	States	Description
Attacked Probability	0..1	This is a counterfactual indication of the contact probability to conduct a terrorist attack.
Possible Target	HVU ID	This is a counterfactual indication of the HVU being a possible target of the contact.
Time to React	Sec	This is a counterfactual indication of the time left to neutralize the contact before the contact will reach its intended target.
Derived Sensed State	Hostile Neutral	These are the states that are derived through the analysis of the available data element by the multi-agent system.

Table 7. Contact Data Elements from Inference

Similarly, one reactive agent is created for each high-value unit (HVU) (Figure 9) and interdiction resource (Figure 10) to monitor the states of the HVU and interdiction resource in the real world, respectively. The description of the data element for the HVU and resources are given in Tables 8 and 9, respectively.

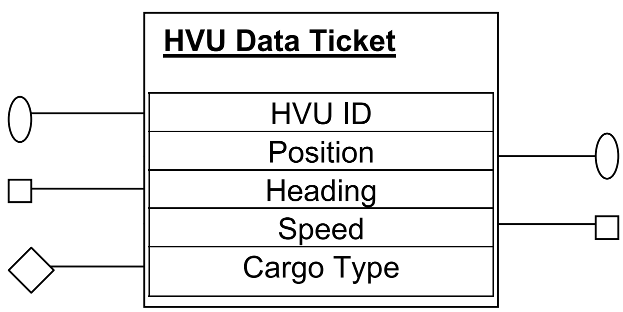


Figure 9. HVU Data Ticket

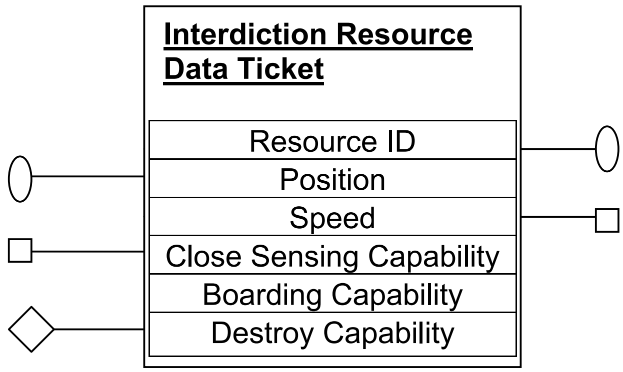


Figure 10. Interdiction Resource Data Ticket

Data element	States	Description
Position	x and y	Cartesian coordinate system in x and y
Heading	0 – 360deg	The heading of the contact
Speed	0 – 50knots	Travel speed of the contact
Cargo type	Flammable Non Flammable	To indicate if this is carrying flammable cargo

Table 8. HVU Data Elements

Data element	States	Description
Position	x and y	Cartesian coordinate system in x and y
Heading	0 – 360deg	The heading of the contact
Close Sensing Capability	True / False	Capability to make close observation
Boarding Capability	True / False	Capability to board the ship
Destroy Capability	True / False	Capability to Sink the contact

Table 9. Interdiction Resource Data Elements

2. Orientation

Contact course-of-action deduction is carried out through the blending network as shown in Figure 11. It is done through a process of composition, completion, and elaboration. The overlapping of mental spaces symbolizes that there are multiple instances of the mental spaces.

During the composition process, each of the generic spaces, which are seeded with a unique combination of HVU and attack tactics, will create a unique hypothesis blend for each new contact that has not been verified neutral. The contact, HVU, and attack tactics are connected through the vital link of predator-prey relationship. The predator (contact) can attack its prey (HVU) using one of the possible attack tactics. The resultant hypothesis blend represents one possible Contact Course-of-Action that is composed of one contact, one HVU, and one tactic. The hypothesis ticket is then released into the membrane for the elaboration process.

The process of completion is done similar to Liebhaber and Feher's [28] surface warfare threat assessment approach. The baseline of each attack tactic probability is first set to 0.5, representing that each new contact has a similar chance of being either hostile or neutral. After which, each of the attack ticket adjusts its probability value autonomously, based on a series of events that bring in pieces of information about the contact. These pieces of information are termed "cues" by Liebhaber and Feher [28]. This process resembles the way an expert conducts threat assessment by increasing or decreasing its threat probability based on a set of cues. The set of cues is listed in Table 10. Each tactic ticket has a goal to predict independently and accurately on the attack probability. An example is shown in Figure 12. In this case, the attack probability of an unknown contact, "BigShip2," attacking "MobileHighValueUnit2" is low.

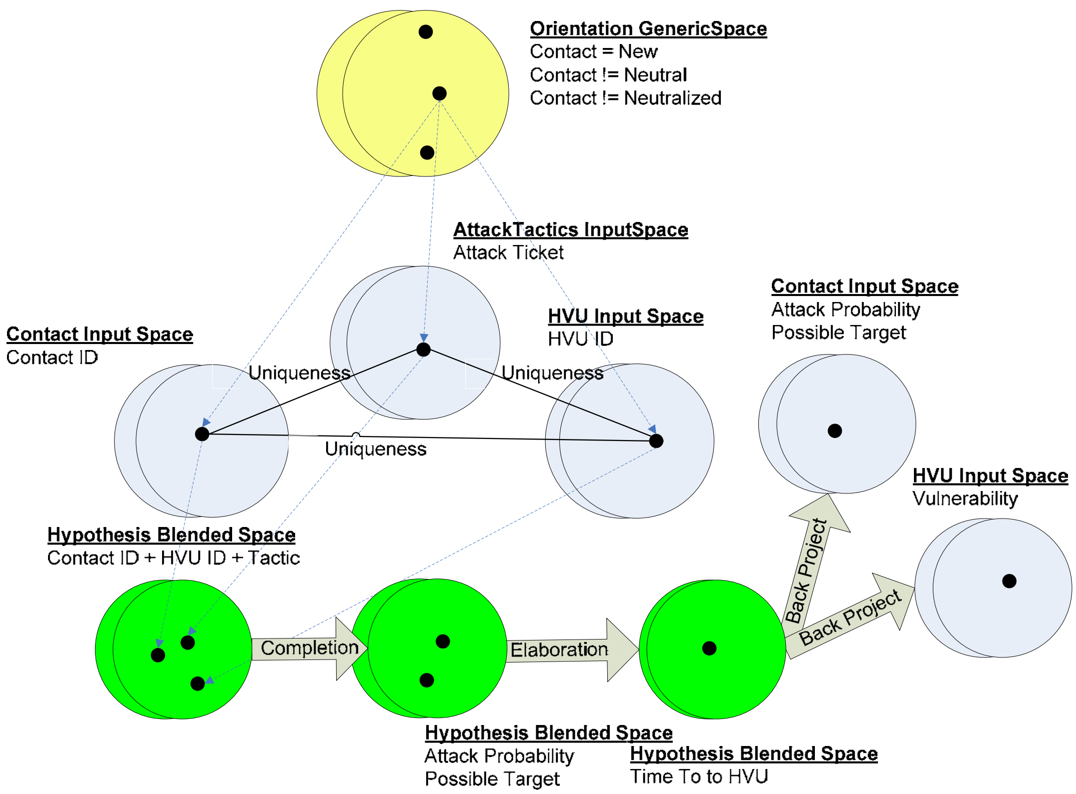


Figure 11. Contact Course-of-Action Deduction Blending Network

The process of elaboration is carried out by taking each of the completed blends and projecting into the future to deduce counterfactual information such as the time of attack. This is similar to the way a human operator conducts mental simulation to determine possible future events. The time of attack will determine the time criticality of the threat.

Cues	States
Proximity Types	Far, Near, Very Near, Too Near
Heading Types	Pulling away, Approaching, Directing at
Speeding	True / False
Origin	Indonesia, Malaysia, SLOC
Craft Size	Small, Big
AIS Discrepancy	True / false
Electronics Intelligence	Neutral, Suspicious

Cues	States
Suspicious Communication	True / false
Crew Size	Normal, Too few, Too many
Crew Behavior	Normal, Abnormal
Small Arm Sighted	True / false
RPG Sighted	True / false
Missile Equipment	True / false
Missile Canister	True / false
Flammable Cargo	True / false
Overloaded	True / false

Table 10. Cues for Threat Assessment

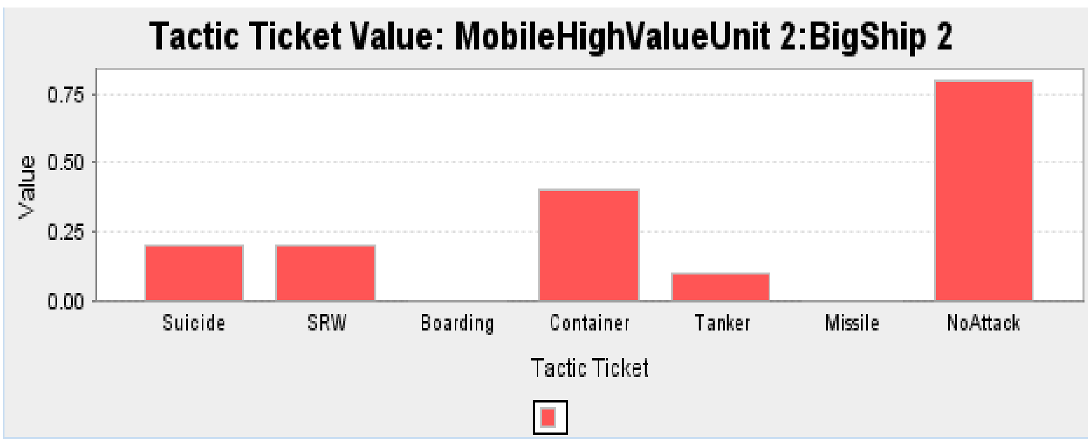


Figure 12. Attack Ticket Predicts Attack Probability Independently

After the blending process is completed, the contact course-of-action with the highest probability of attack will be chosen as the attack tactic. The attack probability, time to react, and the possible target are then back-projected to the contact input space and become part of the input space attributes for use in the subsequent blending process, as shown in Table 10. Similarly, the attack probability against a particular ship will be back-projected to the HVU input space to serve as the HVU vulnerability attribute. The contacts can now be prioritized according to their attack probability as shown in Table 11.

Name	Identity	EngageState	Directivity	AttackProb	Target	Time	Dist
BigShip 2	Unknown	UnEngaged	0.9631366	0.40000004	MobileHighVa...	3.4892051	11.897202
SmallBoat 1	Unknown	UnEngaged	0.98335946	0.39999998	HighValueUni...	29.510721	100.6232
SmallBoat 2	Unknown	UnEngaged	0.98643064	0.39999998	HighValueUni...	36.18444	123.3787
BigShip 1	Unknown	UnEngaged	0.190525	0.3	MobileHighVa...	0.7155624	2.4398654
BigShip 3	Unknown	UnEngaged	0.96100235	0.3	MobileHighVa...	53.73862	183.23349
SmallBoat 3	Unknown	UnEngaged	0.7870112	0.10000005	HighValueUni...	54.1274	184.55911

Table 11. Prioritized Contact Input Space with Back-Projected Information

3. Decision

The decision-making mental process can be further organized into three sub-processes: Goal Analysis, Own Course-of-Action generation and Own Course-of-Action selection.

After a contact course-of-action has been established, a human operator will analyze the situation to determine the Goal to counter each Contact Course-of-Action. Some of the situations and their associated Goals are given in Table 12. The blending network for Goal Analysis is as shown in Figure 13. During composition, the generic space guides the selective projection of elements connected through a cause-effect vital link to the new blend. The completion process then establishes the Goal required, based on the sensed state and attack probability. Finally, the elaboration process computes the time required for the Goal in order to counter the contact course-of-action. After the blending process is completed, the blended information (need and time required) are then back-projected into the Contact Input Space for subsequent processing.

Sensed State and Induced attack probability	Goal
Unknown and low attack probability	To Investigate
Unknown and high attack probability	To Board
Hostile	To Board

Table 12. Situation and Associated Needs

After the Goals have been derived, the next mental process is to derive all possible Own Course-of-Actions (OCOA). In this context, one OCOA means the assignment of one interdiction resource against one contact. If there are m contacts and n resources, there will be n x m possible OCOA. For example, if there are 1,000 contacts and 6 patrol crafts, there are a total of 6,000 possible OCOA.

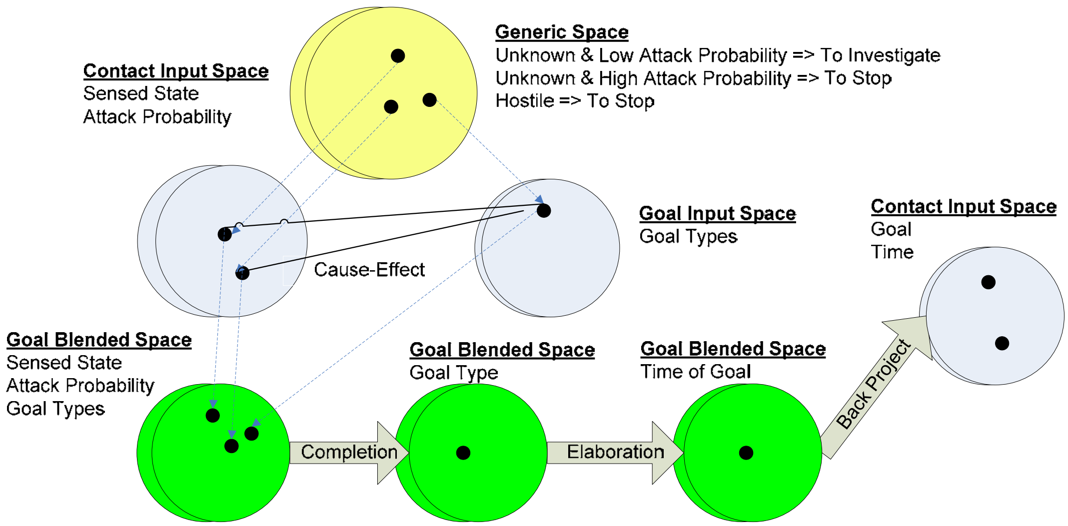


Figure 13. Blending Network for Goals Analysis

The blending network for generating own course-of-actions is given in Figure 14. The composition process generates an OCOA blend for each interdiction resource and contact pair. The completion process then determines if there has been a match in the Goal requirement and capability available. For example, if the Goal specifies a boarding requirement, the unmanned surface vessels, which contain no humans on board, have no capability to board another ship. In this example, there is no match between the Goal and capability. This means that the capability cannot be used to achieve the Goal. The unmatched OCOA will not be discarded at this stage just in case there is no other resource that has a capability to match the need. In such a situation, the Unmanned Surface Vessel will still be deployed to observe the high-prioritized contact. The elaboration process then computes the time required for the interdiction resource to reach the contact. The time to reach is computed as a function of the interdiction resource and contact velocity. The time to reach contact is the effectiveness value. If the mental simulation concluded that the contact would reach its target before the interdiction resource can reach the contact, the ineffective flag will be set.

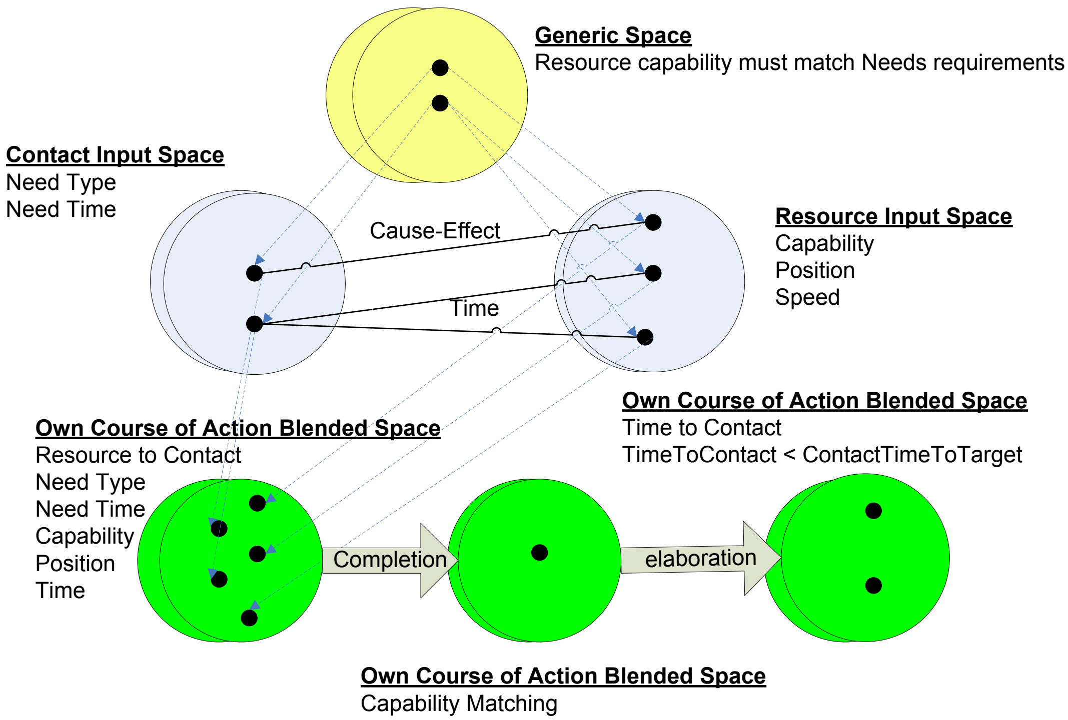


Figure 14. Blending Network for Own Course-of-Action Generation

The blending network for a decision on the course-of-action is as shown in Figure 15. The decision on the course-of-action is done by linear assignment using Munkras' algorithm [57] with effectiveness as the cost. However, before the linear assignment is carried, the Contact Input Spaces must be sorted according to attack probability. After which, the n number of the highest attack probability contact are selected for the assignment process. The n is the number of available interdiction resources. After which, the initial list of possible OCOA is reduced by culling the course-of-actions that are not in the top-priority list. The effectiveness of the reduced course-of-actions list is then formulated into the cost matrix as input to Munkras' algorithm. After the assignment process, if none of the interdictions are able to reach the contact in time before it reaches its hypothesized target, an emergency interdiction helicopter will be deployed.

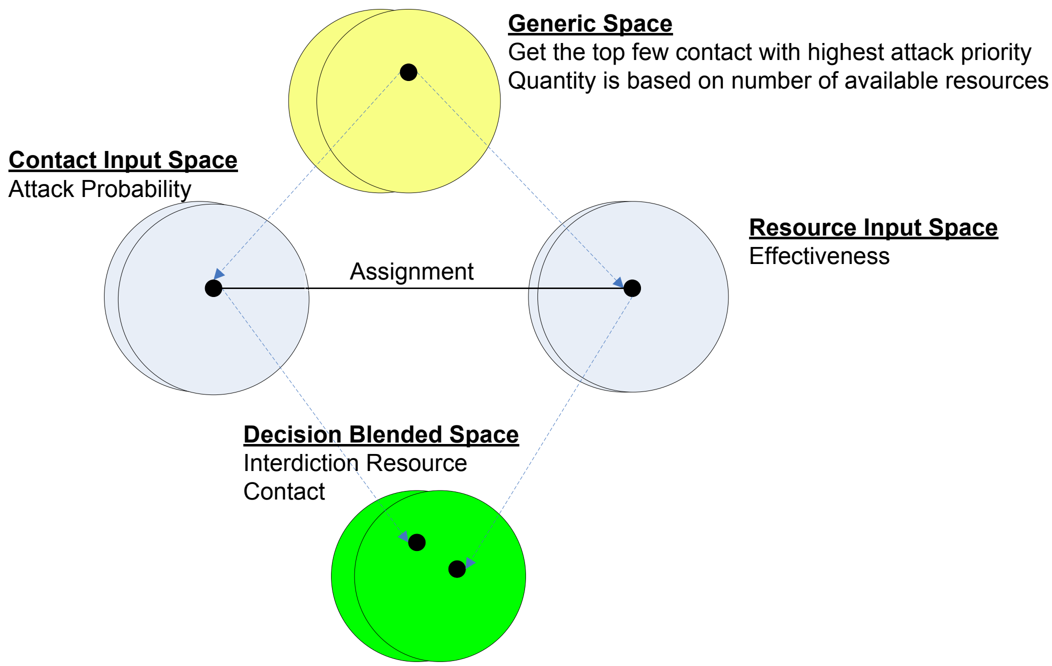


Figure 15. Blending Network for Own Course-of-action Decision

4. Action

After the assignment process, the course-of-actions are disseminated out to the interdiction resources for execution. The Observation-Orientation-Decision-Action mental process is repeated immediately in order to allow continual assessment and dynamic reassignment should a higher priority threat appear.

D. CONCLUSION

In this chapter, the mental process of the plan generation guided by Boyd's OODA loop theory has been described. It has been shown that the entire mental process can be meaningfully described using the novel conceptual blending theory. The blending process can then be implemented using the NPS's proven software blending technologies made available in the Java-based CMAS library.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. IMPLEMENTATION AND TESTING

A. INTRODUCTION

The first research question is to determine whether the conceptual blending theory [26] can be used to model an expert's mental process to generate plans for maritime interdiction. The mental process is based on Boyd's OODA loop theory [13]. The second research question is to determine whether the bio-inspired operator "ticket" can be used to deduce contact course-of-action [27]. The third research question is to determine whether software blending that is implemented using the Compounded Multi-Agent System (CMAS) library [27] can be used to support real-time plan generation. The output from the plan generation process has two by-products: Contact Course-of-Action (CCOA) analysis, and Interdiction Resources Course-of-Action development (IRCOA).

The design of Boyd's OODA mental process using conceptual blending theory was described in the previous chapter. The use of a bio-inspired operator "ticket" was described. To test the hypotheses, the above-mentioned theories must be applied in a maritime interdiction environment. As this is just a concept demonstrator, integration with a live Vehicle Traffic Service System is not desirable. Henceforth, a simulator was used to simulate the shipping traffic, high-value units, and interdiction resources in the straits of Singapore.

This chapter describes the simulator development and various tests carried out to determine the performance of the Plan Generation Software.

B. SIMULATOR DEVELOPMENT

Several simulators have been evaluated to provide input to test the Plan Generation Software. The Simkit-based simulator, developed and used for the NPS SEA Integrated Project for Port Security Strategy 2012 [29], was chosen because of our familiarity with Simkit and Java Programming language. Several modifications were made in order for the simulator to serve its intended purpose. The list of enhancements is given in Table 13.

Enhancement	Description
Contact Attributes	In addition to the kinematic attributes of the ships, other attributes were added to provide additional inputs to simulate the data available from the Automatic Identification System, intelligence, and visual reports.
Terrorist Behavior	The behavior of terrorists has been enhanced to allow the user to choose from a set of available start positions and targets. The terrorists have the option of moving directly to the target or to follow the sea lane and turn toward the target at the Closest Point of Approach along the sea lane. The terrorist can also follow a ship to simulate a boarding attempt. The terrorist configuration panel is shown in Figure 16.
Interdiction Resource Behavior	Instead of following a scripted path, the interdiction resources were enhanced to take tasking instructions from the Plan Generation Software and conduct a pursuit operation against an assigned contact. The interdiction resource will chase the target until the target is neutralized, verified neutral, or reassigned to another interdiction resource.
Display	The map was also changed from the port of Oakland to the strait of Singapore. The icon colors were changed to reflect the state of the contact: unknown (yellow), neutral (light green), inferred neutral (dark green), inferred hostile (magenta), hostile (red), and neutralized (white). The display is shown in Figure 17.

Table 13. Enhancement to Simulators

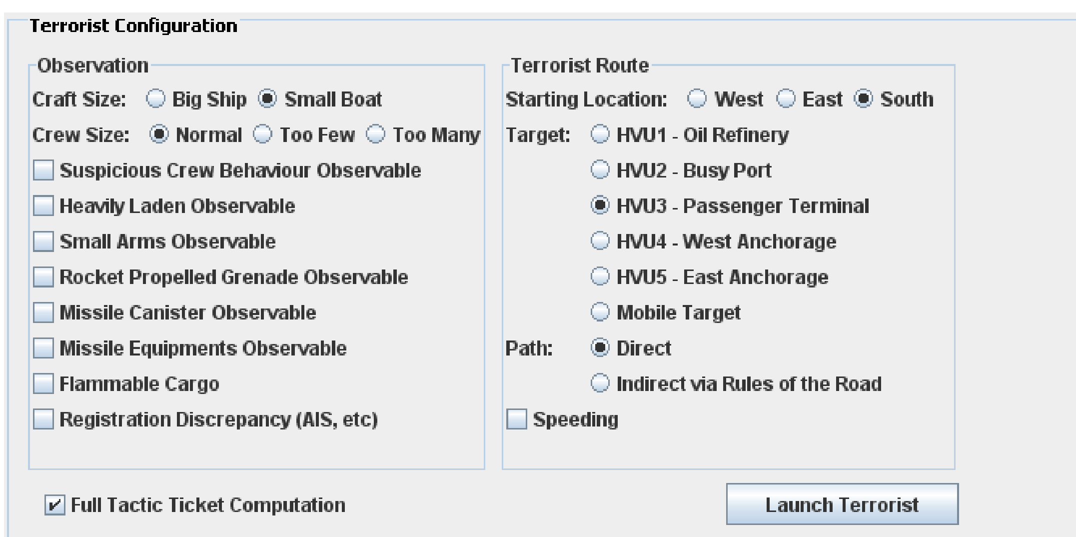


Figure 16. Terrorist Configuration Panel

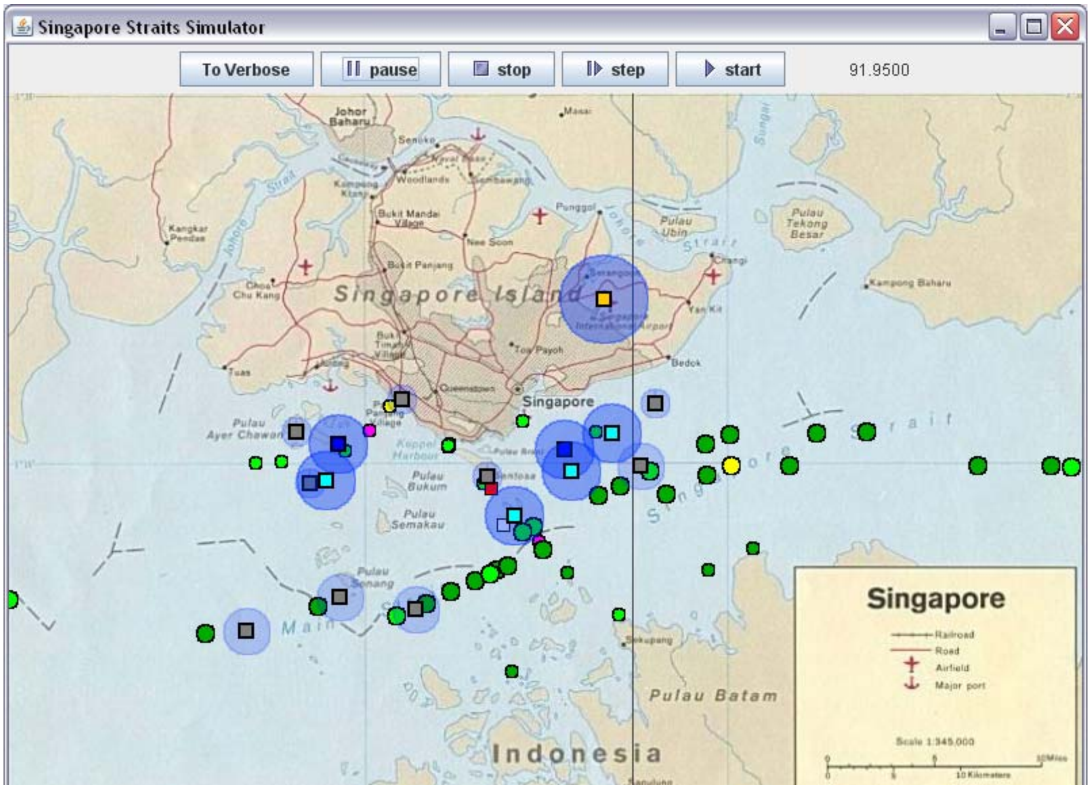


Figure 17. Adaptive Display of Situational Picture

C. PLAN GENERATION SOFTWARE DEVELOPMENT

Before the Plan Generation Software can be run, it needs to be configured with the threat assessment experience. After the experience is configured, the Plan generation will take in contact information from the simulated Vessel Traffic Service System, High Value Unit Monitoring System, and Interdiction Resources from the simulator to generate the plan. The plan is expressed in terms of Interdiction Resource to Contact Assignment. The inferred Contact Course-of-Action can then be used for adaptive display purposes. The system architecture is shown in Figure 18.

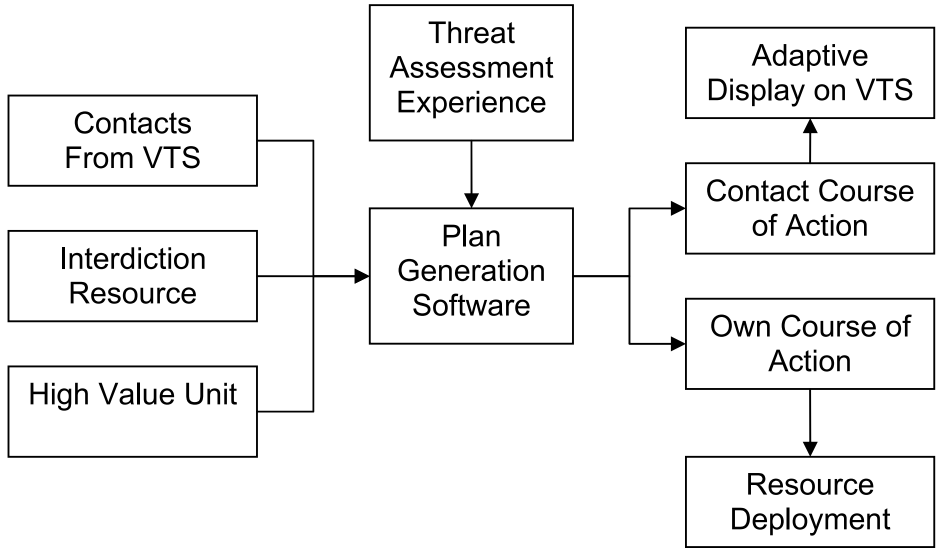
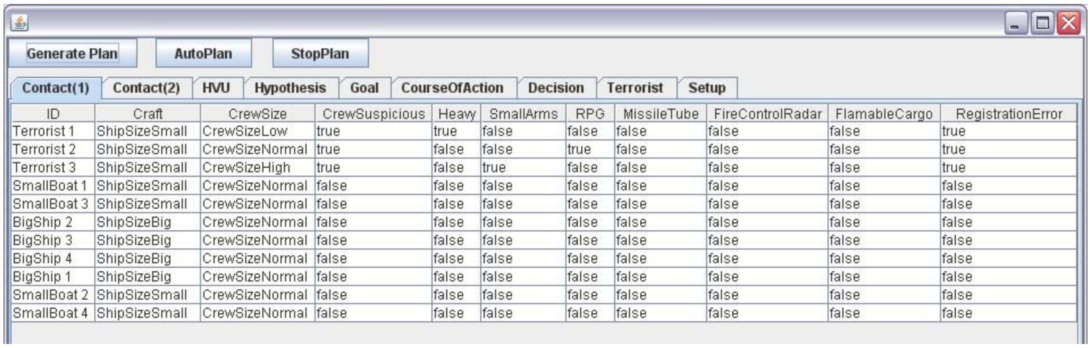


Figure 18. Plan Generation Software Architecture

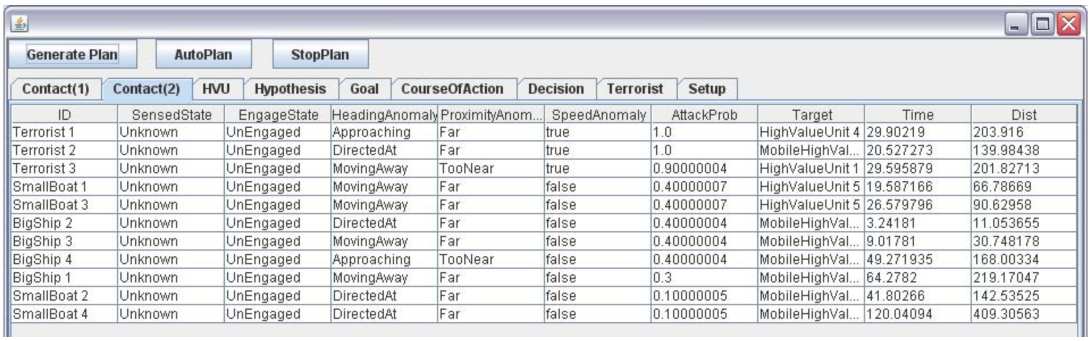
The threat assessment experience was compiled from a group of Naval Surface Warfare Officers from Singapore and the U.S. Navy through a survey. The survey was conducted to understand how experienced surface warfare officers conduct threat assessment based on a set of cues. This is the same approach used by Liebhaber and Feher [28] to capture threat assessment experience from experts in air and surface warfare domains.

The mental spaces are displayed in the form of a table in the Plan Generation Software as shown in Figures 19 through 26. The display of mental spaces will allow the operator to look at the mental spaces to determine how the plans are generated. Figures 19 and 20 display the Contact Input Space. The attributes in Figure 19 come mainly from AIS, visual observation, and intelligence systems, while Figure 20 describes the kinematic attributes and information that are back-projected from the blending process. The back-projected attributes are Attack Probability, Possible Target, Time of Strike, and Distance to Target. Note that the threat input spaces are already sorted according to the attack probability.



ID	Craft	CrewSize	CrewSuspicious	Heavy	SmallArms	RPG	MissileTube	FireControlRadar	FlamableCargo	RegistrationError
Terrorist 1	ShipSizeSmall	CrewSizeLow	true	true	false	false	false	false	false	true
Terrorist 2	ShipSizeSmall	CrewSizeNormal	true	false	false	true	false	false	false	true
Terrorist 3	ShipSizeSmall	CrewSizeHigh	true	false	true	false	false	false	false	true
SmallBoat 1	ShipSizeSmall	CrewSizeNormal	false	false	false	false	false	false	false	false
SmallBoat 3	ShipSizeSmall	CrewSizeNormal	false	false	false	false	false	false	false	false
BigShip 2	ShipSizeBig	CrewSizeNormal	false	false	false	false	false	false	false	false
BigShip 3	ShipSizeBig	CrewSizeNormal	false	false	false	false	false	false	false	false
BigShip 4	ShipSizeBig	CrewSizeNormal	false	false	false	false	false	false	false	false
BigShip 1	ShipSizeBig	CrewSizeNormal	false	false	false	false	false	false	false	false
SmallBoat 2	ShipSizeSmall	CrewSizeNormal	false	false	false	false	false	false	false	false
SmallBoat 4	ShipSizeSmall	CrewSizeNormal	false	false	false	false	false	false	false	false

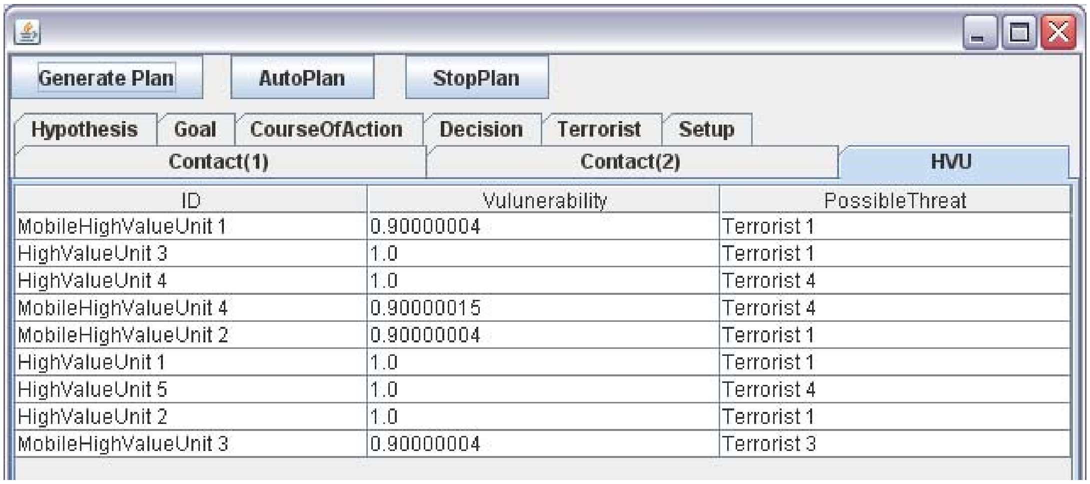
Figure 19. Contact Cues Set 1



ID	SensedState	EngageState	HeadingAnomaly	ProximityAnom...	SpeedAnomaly	AttackProb	Target	Time	Dist
Terrorist 1	Unknown	UnEngaged	Approaching	Far	true	1.0	HighValueUnit 4	29.90219	203.916
Terrorist 2	Unknown	UnEngaged	DirectedAt	Far	true	1.0	MobileHighVal...	20.527273	139.98438
Terrorist 3	Unknown	UnEngaged	MovingAway	TooNear	true	0.90000004	HighValueUnit 1	29.595879	201.82713
SmallBoat 1	Unknown	UnEngaged	MovingAway	Far	false	0.40000007	HighValueUnit 5	19.587166	66.78669
SmallBoat 3	Unknown	UnEngaged	MovingAway	Far	false	0.40000007	HighValueUnit 5	26.579796	90.62958
BigShip 2	Unknown	UnEngaged	DirectedAt	Far	false	0.40000004	MobileHighVal...	3.24181	11.053655
BigShip 3	Unknown	UnEngaged	MovingAway	Far	false	0.40000004	MobileHighVal...	9.01781	30.748178
BigShip 4	Unknown	UnEngaged	Approaching	TooNear	false	0.40000004	MobileHighVal...	49.271935	168.00334
BigShip 1	Unknown	UnEngaged	MovingAway	Far	false	0.3	MobileHighVal...	64.2782	219.17047
SmallBoat 2	Unknown	UnEngaged	DirectedAt	Far	false	0.10000005	MobileHighVal...	41.80266	142.53525
SmallBoat 4	Unknown	UnEngaged	DirectedAt	Far	false	0.10000005	MobileHighVal...	120.04094	409.30563

Figure 20. Contact Cues Set 2

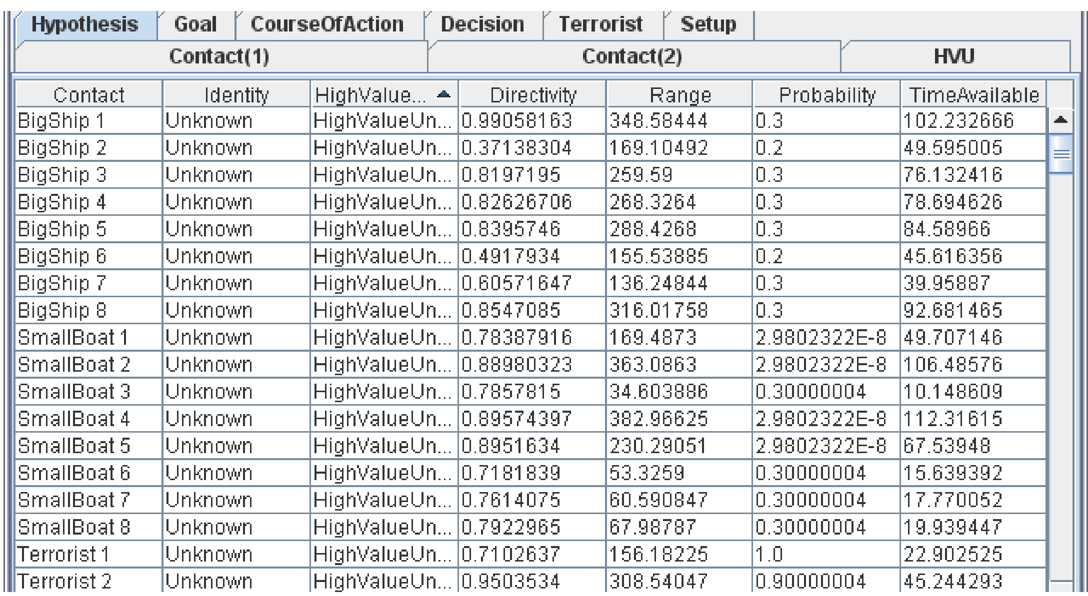
The high-value unit (HVU) input space is shown in Figure 21. The attributes of vulnerability and possible threat are back-projected attributes from the blending process, indicating the vulnerability of this HVU, which is prone to terrorist attack, and the possible hostile ship. Note that the vulnerability attribute is the same as the attack probability of the possible ship. The attack probability of 0.9 means that the HVU is 90 percent vulnerable and subjected to be strike.



ID	Vulunerability	PossibleThreat
MobileHighValueUnit 1	0.90000004	Terrorist 1
HighValueUnit 3	1.0	Terrorist 1
HighValueUnit 4	1.0	Terrorist 4
MobileHighValueUnit 4	0.90000015	Terrorist 4
MobileHighValueUnit 2	0.90000004	Terrorist 1
HighValueUnit 1	1.0	Terrorist 1
HighValueUnit 5	1.0	Terrorist 4
HighValueUnit 2	1.0	Terrorist 1
MobileHighValueUnit 3	0.90000004	Terrorist 3

Figure 21. HVU Input Space

The hypothesis blended space is shown in Figure 22. The hypothesis blended space lists out all possible targets and tactics that a particular contact might strike. The probability of attack is computed based on the threat assessment model described earlier during our descriptions of the completion process. The available time indicates the time duration before the contact will hit the target.



Contact	Identity	HighValue...	Directivity	Range	Probability	TimeAvailable
BigShip 1	Unknown	HighValueUn...	0.99058163	348.58444	0.3	102.232666
BigShip 2	Unknown	HighValueUn...	0.37138304	169.10492	0.2	49.595005
BigShip 3	Unknown	HighValueUn...	0.8197195	259.59	0.3	76.132416
BigShip 4	Unknown	HighValueUn...	0.82626706	268.3264	0.3	78.694626
BigShip 5	Unknown	HighValueUn...	0.8395746	288.4268	0.3	84.58966
BigShip 6	Unknown	HighValueUn...	0.4917934	155.53885	0.2	45.616356
BigShip 7	Unknown	HighValueUn...	0.60571647	136.24844	0.3	39.95887
BigShip 8	Unknown	HighValueUn...	0.8547085	316.01758	0.3	92.681465
SmallBoat 1	Unknown	HighValueUn...	0.78387916	169.4873	2.9802322E-8	49.707146
SmallBoat 2	Unknown	HighValueUn...	0.88980323	363.0863	2.9802322E-8	106.48576
SmallBoat 3	Unknown	HighValueUn...	0.7857815	34.603886	0.30000004	10.148609
SmallBoat 4	Unknown	HighValueUn...	0.89574397	382.96625	2.9802322E-8	112.31615
SmallBoat 5	Unknown	HighValueUn...	0.8951634	230.29051	2.9802322E-8	67.53948
SmallBoat 6	Unknown	HighValueUn...	0.7181839	53.3259	0.30000004	15.639392
SmallBoat 7	Unknown	HighValueUn...	0.7614075	60.590847	0.30000004	17.770052
SmallBoat 8	Unknown	HighValueUn...	0.7922965	67.98787	0.30000004	19.939447
Terrorist 1	Unknown	HighValueUn...	0.7102637	156.18225	1.0	22.902525
Terrorist 2	Unknown	HighValueUn...	0.9503534	308.54047	0.90000004	45.244293

Figure 22. Hypothesis Blended Space

The probability estimates pattern for attack tactics in each contact and HVU pair is shown in Figure 23, which describes a case in which the attack probability for BigShip 2 against Mobile HVU3 is pretty low.

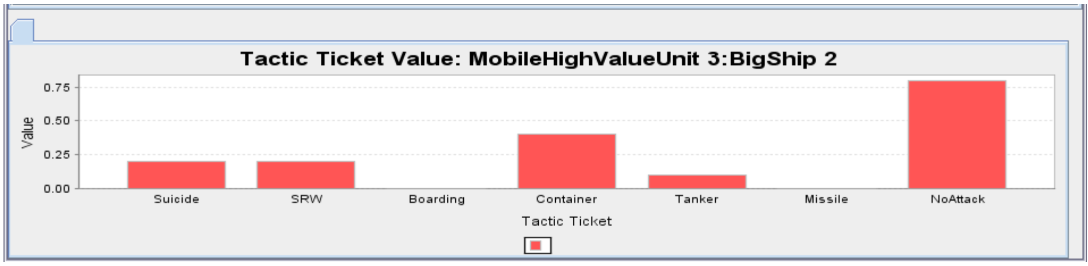
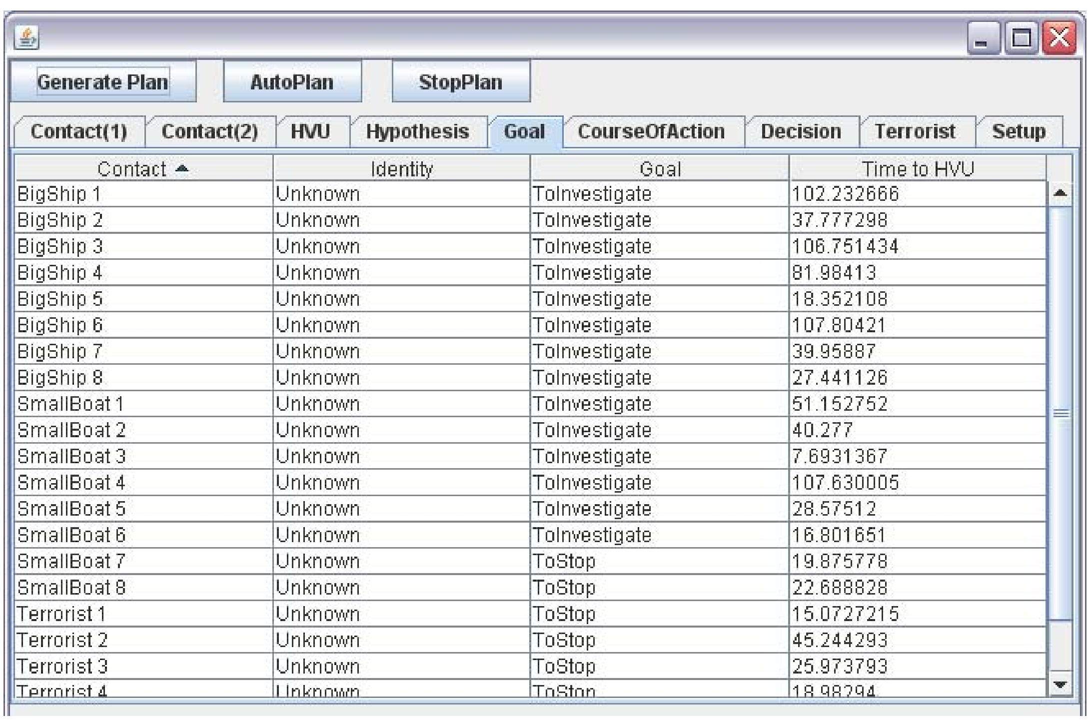


Figure 23. Hypothesis Blended Space

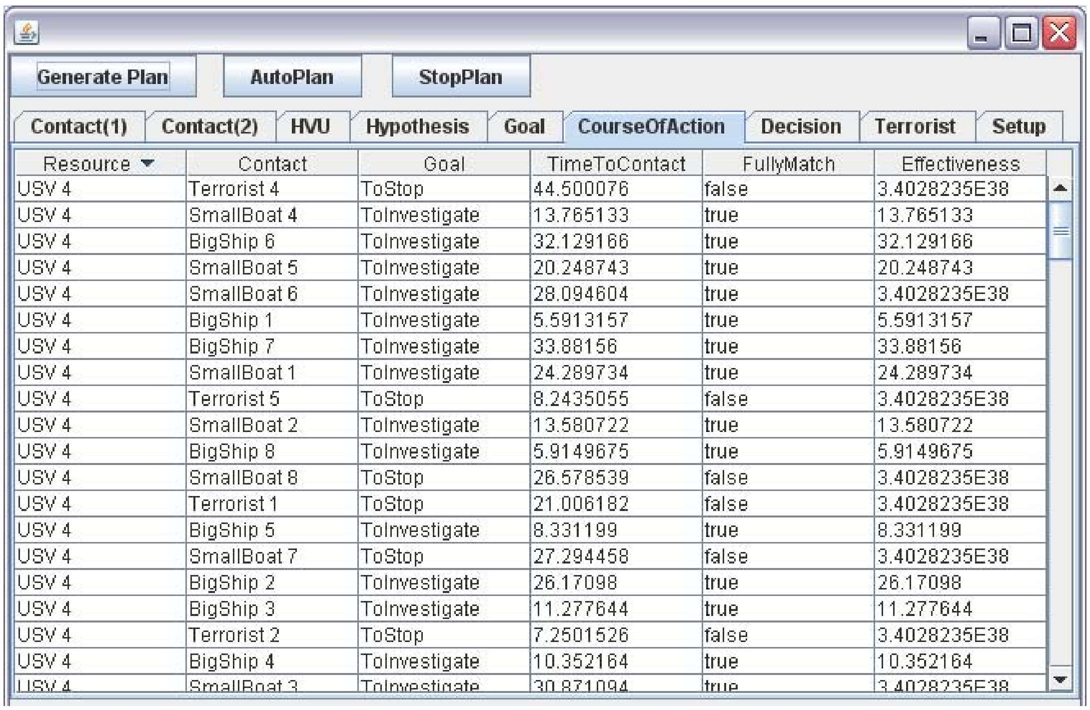
The goal generated for each contact is shown in Figure 24. The goal is determined based on the sensed state and the inferred attack probability. If the inferred sensed state is hostile, the goal is to stop the ship. Otherwise, the goal is to investigate the ship for positive identification.



Contact	Identity	Goal	Time to HVU
BigShip 1	Unknown	ToInvestigate	102.232666
BigShip 2	Unknown	ToInvestigate	37.777298
BigShip 3	Unknown	ToInvestigate	106.751434
BigShip 4	Unknown	ToInvestigate	81.98413
BigShip 5	Unknown	ToInvestigate	18.352108
BigShip 6	Unknown	ToInvestigate	107.80421
BigShip 7	Unknown	ToInvestigate	39.95887
BigShip 8	Unknown	ToInvestigate	27.441126
SmallBoat 1	Unknown	ToInvestigate	51.152752
SmallBoat 2	Unknown	ToInvestigate	40.277
SmallBoat 3	Unknown	ToInvestigate	7.6931367
SmallBoat 4	Unknown	ToInvestigate	107.630005
SmallBoat 5	Unknown	ToInvestigate	28.57512
SmallBoat 6	Unknown	ToInvestigate	16.801651
SmallBoat 7	Unknown	ToStop	19.875778
SmallBoat 8	Unknown	ToStop	22.688828
Terrorist 1	Unknown	ToStop	15.0727215
Terrorist 2	Unknown	ToStop	45.244293
Terrorist 3	Unknown	ToStop	25.973793
Terrorist 4	Unknown	ToStop	18.98294

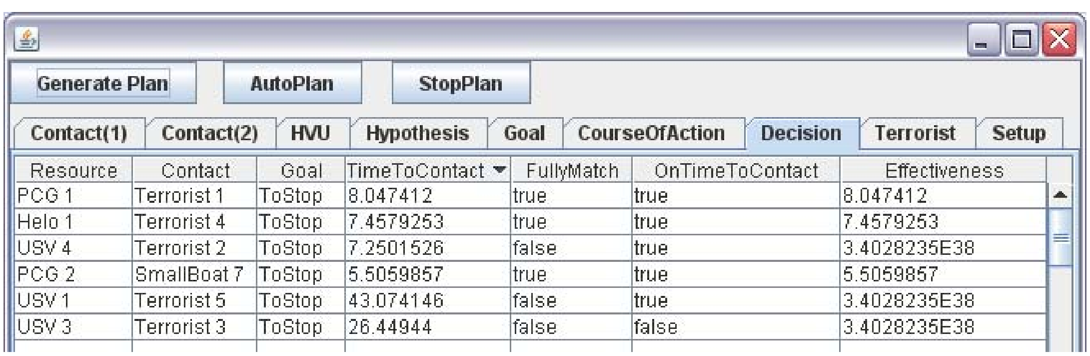
Figure 24. Goal Generation

The possible course-of-actions for each interdiction resource are shown in Figure 25. Each resource-to-contact pair is a possible course-of-action. Each course-of-action is evaluated based on an effectiveness attribute, which is determined by the time for the resource to get to the contact as well as goal satisfaction by the resources. After the evaluation of all possible course-of-actions, the decision is made by considering the number of resources available and the prioritized contact through a linear assignment process. The decision on the course-of-action is as shown in Figure 26.



Resource	Contact	Goal	TimeToContact	FullyMatch	Effectiveness
USV 4	Terrorist 4	ToStop	44.500076	false	3.4028235E38
USV 4	SmallBoat 4	ToInvestigate	13.765133	true	13.765133
USV 4	BigShip 6	ToInvestigate	32.129166	true	32.129166
USV 4	SmallBoat 5	ToInvestigate	20.248743	true	20.248743
USV 4	SmallBoat 6	ToInvestigate	28.094604	true	3.4028235E38
USV 4	BigShip 1	ToInvestigate	5.5913157	true	5.5913157
USV 4	BigShip 7	ToInvestigate	33.88156	true	33.88156
USV 4	SmallBoat 1	ToInvestigate	24.289734	true	24.289734
USV 4	Terrorist 5	ToStop	8.2435055	false	3.4028235E38
USV 4	SmallBoat 2	ToInvestigate	13.580722	true	13.580722
USV 4	BigShip 8	ToInvestigate	5.9149675	true	5.9149675
USV 4	SmallBoat 8	ToStop	26.578539	false	3.4028235E38
USV 4	Terrorist 1	ToStop	21.006182	false	3.4028235E38
USV 4	BigShip 5	ToInvestigate	8.331199	true	8.331199
USV 4	SmallBoat 7	ToStop	27.294458	false	3.4028235E38
USV 4	BigShip 2	ToInvestigate	26.17098	true	26.17098
USV 4	BigShip 3	ToInvestigate	11.277644	true	11.277644
USV 4	Terrorist 2	ToStop	7.2501526	false	3.4028235E38
USV 4	BigShip 4	ToInvestigate	10.352164	true	10.352164
USV 4	SmallBoat 3	ToInvestigate	30.871094	true	3.4028235E38

Figure 25. Course-of-Actions



Resource	Contact	Goal	TimeToContact	FullyMatch	OnTimeToContact	Effectiveness
PCG 1	Terrorist 1	ToStop	8.047412	true	true	8.047412
Helo 1	Terrorist 4	ToStop	7.4579253	true	true	7.4579253
USV 4	Terrorist 2	ToStop	7.2501526	false	true	3.4028235E38
PCG 2	SmallBoat 7	ToStop	5.5059857	true	true	5.5059857
USV 1	Terrorist 5	ToStop	43.074146	false	true	3.4028235E38
USV 3	Terrorist 3	ToStop	26.44944	false	false	3.4028235E38

Figure 26. Decision

D. VERIFICATION AND VALIDATION

The verification and validation strategy is based on the recommendations provided by Sargent [59]. The simulator and Plan Generation Software were presented to several experienced littoral water surface warfare officers and command and control engineers. The survey form and the survey results are given in Appendix C and Appendix D respectively. They were first presented with a cluttered scenario as shown in Figure 27. Within the scenario, there are four unmanned surface vessels, two patrol craft, and nine mobile and static high-value units. The yellow icons symbolize “unknown.” They were then asked to describe how a human operator would conduct situational assessment and plan for maritime interdiction. After which, the plan generation was executed and the adaptive display was shown to them as in Figure 28. The darker green color icons symbolize “inferred neutral” while the moron color represents “inferred hostile.”

Figure 27. Cluttered Environment along Singapore Straits.

Figure 28. Situational Awareness Display

The pattern that resembles a suicide bombing attack is shown in Figure 29. The pattern that resembles a short-range weapon attack is shown in Figure 30. The pattern that resembles a boarding attack is shown in Figure 31. The pattern that resembles a huge mass attack is shown in Figure 32. The pattern that resembles a high-energy attack is shown in Figure 33. The pattern that resembles a missile attack is shown in Figure 34.

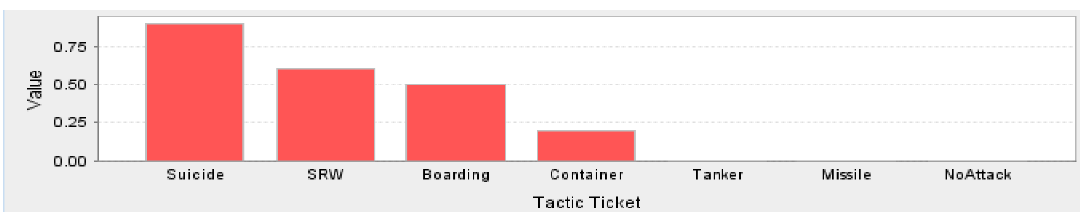


Figure 29. Suicide Bombing Probability Estimates Pattern

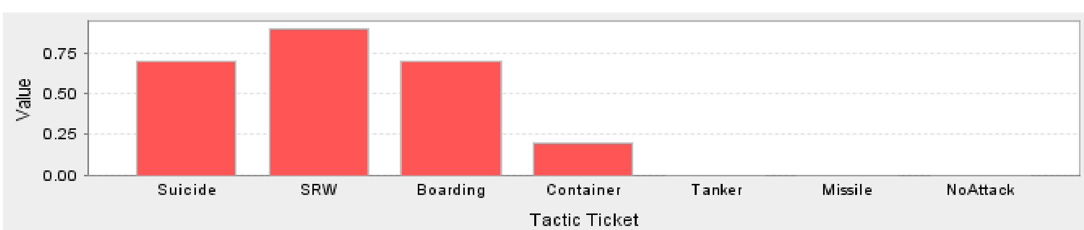


Figure 30. Short-Range Weapon Attack Probability Estimates Pattern

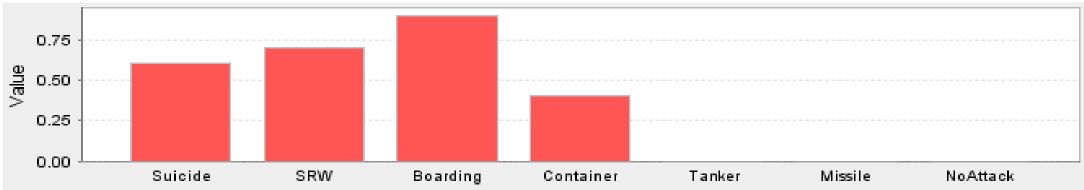


Figure 31. Boarding Attack Probability Estimates Pattern

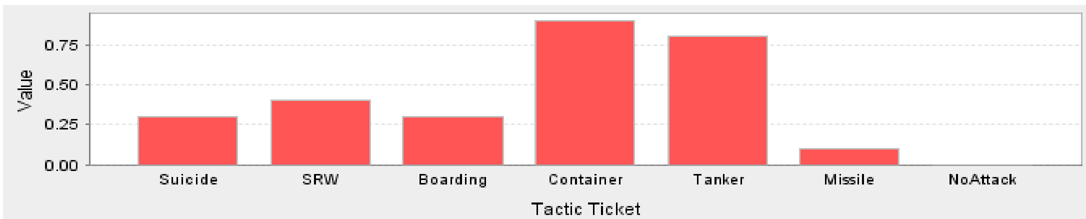


Figure 32. Huge Mass Attack Probability Estimates Pattern

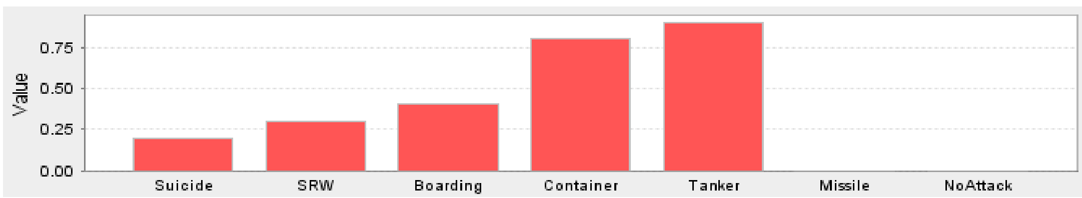


Figure 33. High-Energy Attack Probability Estimates Pattern

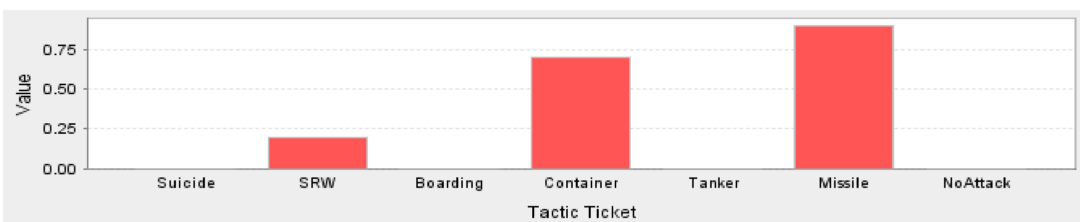


Figure 34. Missile Attack Probability Estimates Pattern

The conceptual model validity was carried out by using the common military decision-making conceptual model described by Boyd's OODA Loop Theory [23]. The interviewees indicated that Boyd's conceptual model resembles the way they make decisions in a littoral surface warfare context. Computerized model verification was carried out by looking at reactive agents' attributes and determining the mental spaces computed through the graphical user interface. For example, with eight high-value units and a hundred (100) contacts, there were eight hundred (800) hypotheses created and evaluated. Operational validity was carried out by asking whether the mental pattern of the computed Attack Probability Estimates resembles that of an experienced surface warfare officer. The interviewees indicated that the computed mental pattern does resemble that of an expert. Data validity was carried out by interviewing several experienced littoral water warfare officers and by de-conflicting some of the data collected. Although experts may process cues differently, the differences were presented to ask for their second opinions and allow them to adjust their opinions.

Some of the techniques used in the verification and validation processes were Animation, Degenerate Tests, Extreme Condition Tests, Face Validity, Fixed Values, Internal Validity, and Turing Tests. The simulator provides the animation. The kinematics of each contact can be observed in the animation while the decision made by the plan generation software can also be observed through the approach taken by the interdiction resources. One example is that of a terrorist ship approaching one high-value unit from afar. The attack probability constantly adjusts itself as the terrorist approaches the high-value unit.

Degenerate Tests were used to determine if the plan generator software would produce the expected attack probability given a set of contact attributes as shown in Figures 29 through 34. Extreme Condition Tests were carried out by using the extremes of both contact data attributes available. For example, in some cases, only kinematics and AIS information were available, while in other cases, visual information was available through spot reports. For Face Validity, the interviewees were asked to observe the entire mental process calculated and to determine whether the process resembles that of an expert. In the Fixed Values test, the speed and capability of interdiction resources were changed to analyze the effect on the effectiveness computation and decision-making processes. Internal Validity was used to see if the plan generation software generates a similar set of results with a similar set of cues. Turing Tests was conducted by asking the interviewees to see if they could tell whether the decisions were computed by the plan generation software or a human expert.

The interviewees agreed that the above Probability Estimates Patterns describe a possible means to represent an expert's mental pattern in a situational recognition process. For example, Figure 35 can represent a mental pattern in which, although a short-range weapon attack pattern is high, the other form of attacks, such as suicide bombing and boarding, are also possible. According to the survey results, the Navy officers and engineers indicated that the threat analysis resembles how an expert would conduct surface warfare threat assessment. Although they agreed that human operators would be able to do the job, the task of monitoring a cluttered environment would be greatly enhanced by such a decision support tool. As for planning of own course-of-actions, most interviewees expressed that an optimal planning system such as this Plan Generation Software based on threat intention and effectiveness would be very beneficial as a decision support tool.

E. BEYOND EXPERIENCE HANDLING

The above probability estimate patterns describe a typical situational pattern. However, the real-world environment may present an atypical set of cues that might be either contradictory or ambiguous. Under such circumstances, Klein [40] writes that the human expert is able to recognize the threat and act accordingly.

The probability estimate pattern is also able to represent such an atypical pattern, for example, the pattern for a bombing attack as shown in Figure 29. When conducting suicide bombing, suppose that the terrorist usually does not carry a weapon but only bombs. However, should an atypical pattern exist in which a suicide attacker does carry a weapon; the corresponding pattern is as described in Figure 35. Comparing this pattern with the typical pattern shown in Figure 29, the atypical pattern suggests that both short-range and suicide bombing attacks are equally possible. A boarding attack, however, is low probability because of other factors such as not enough manpower to board a ship.

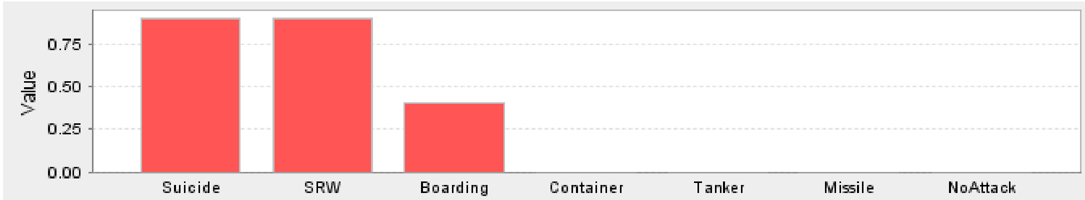


Figure 35. Missile Attack Probability Estimates Pattern

F. PERFORMANCE ANALYSIS

Several types of tests are conducted to test the performance and usefulness of the Plan Generation Software:

a. Comparison of the performance with and without the plan generation software.

b. Comparison of the performance with and without a threat assessment Plan Generation

c. Computation Time Analysis.

1. Comparison of Performance with and without the Plan Generation Software

Without the plan generation software, the patrol profile of each interdiction resource might be preplanned or scripted. The patrol profile of each interdiction resource is as shown in Figure 36.

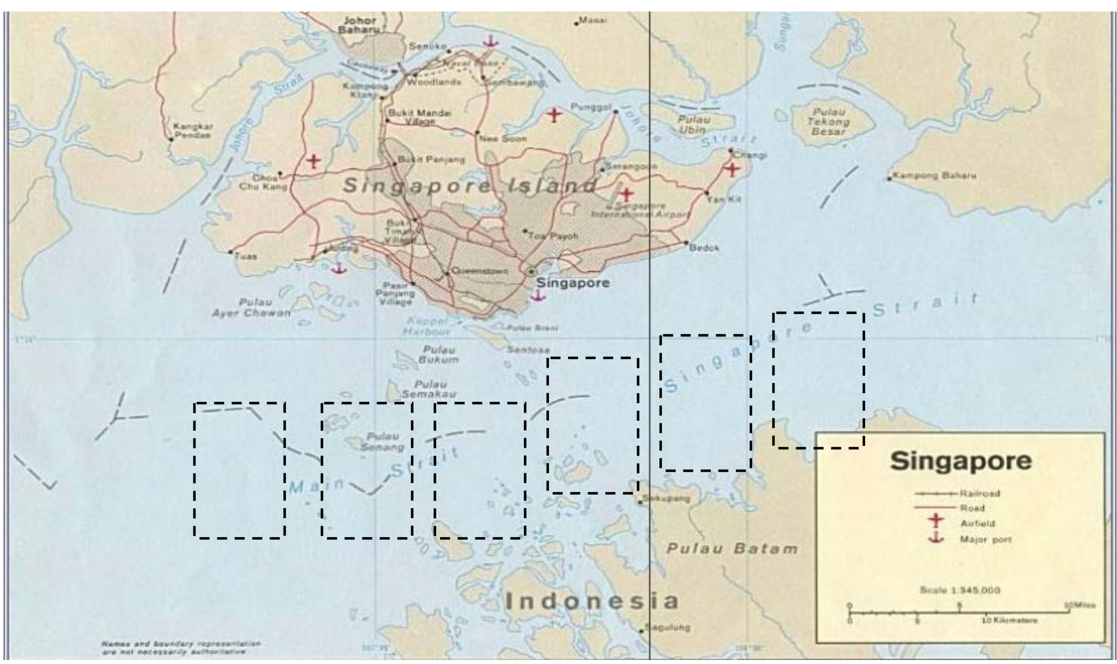


Figure 36. Scripted Interdiction Patrol Profile

For the scenario with the plan generation software, the interdiction resources are stationed at their respective positions as marked by the blue and Cyan squares as shown in Figure 37. The dark green represents an inferred neutral while the light green represents a verified neutral. The maroon color represents an inferred hostile. In this scenario, there are a total of a hundred (100) neutral ships and ten (10) terrorists.

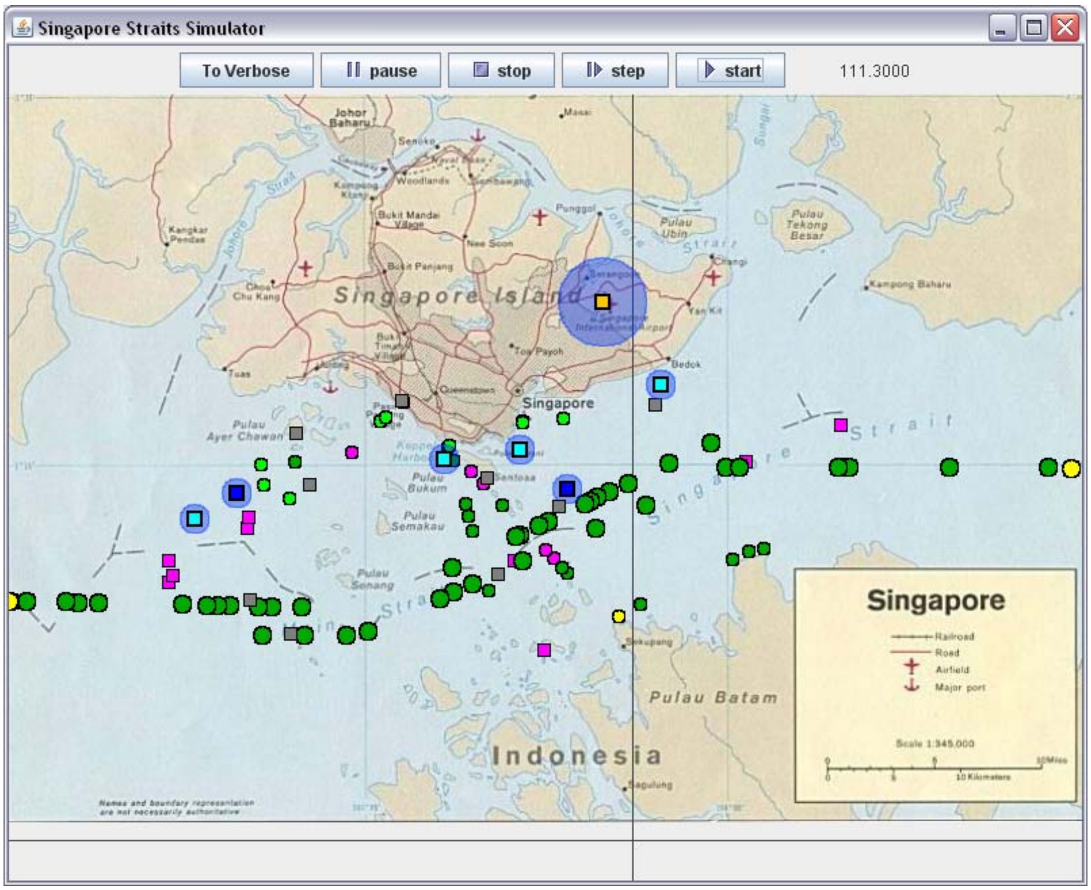


Figure 37. Scenario to Test Plan Generation Software

In both test cases, ten terrorists were launched from three positions (west, south, and east) to attack five high-value unit installations. The measure of effectiveness (MOE) is based on the percentage of terrorists neutralized and the percentage of neutral shipping identified as neutral. The results are shown below. In this comparison, since the scripted mode is unable to model pursuit and different capabilities of interdiction, the level of details has been simplified to allow instant terrorist suppression and USV boarding capability. The results are shown in Figure 38.

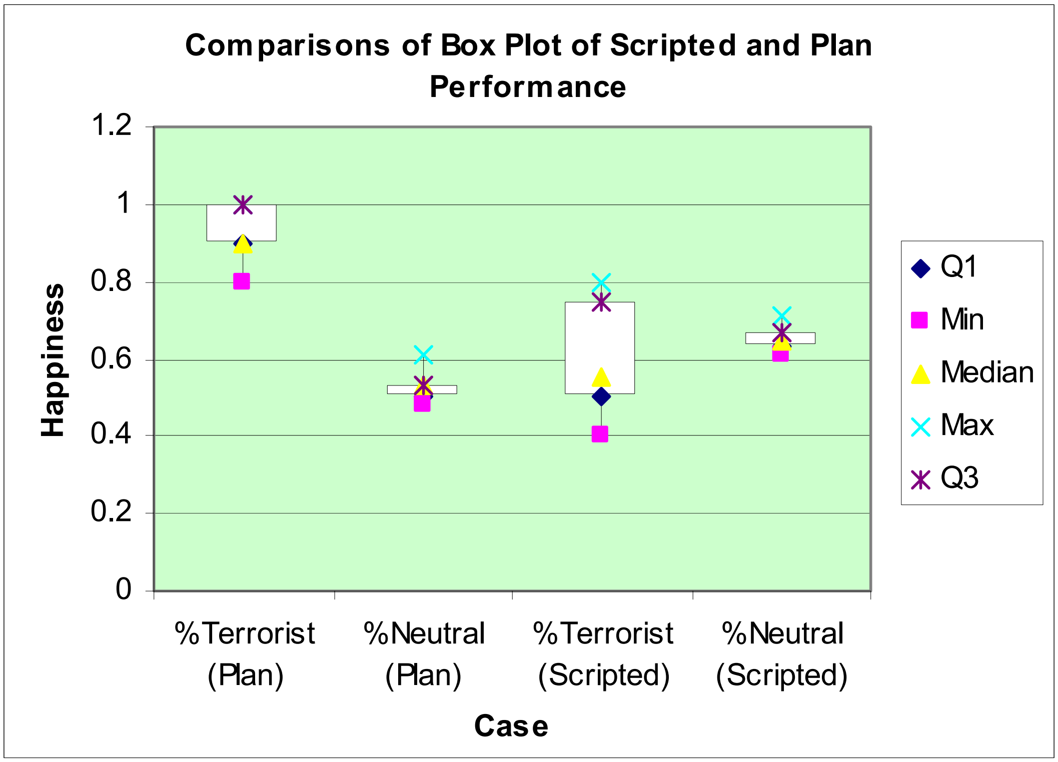


Figure 38. Comparison of Planned Profile with Scripted Profile

From Figure 38, the planned profile by the Plan Generation Software was able to neutralize most of the terrorists while the scripted profile was only able to neutralize around 60 percent of the terrorists by chance. The scripted profile was able to investigate more neutral ships, because the scripted profiles are in the midst of the shipping traffic. The planned profile investigated fewer neutral ships because more emphasis was being placed on high-priority threats, which resulted in its investigating ships that were farther away. The lesser number of neutral ships being investigated may not imply lower performance, but rather higher efficiency without unnecessary investigation and yet an ability to achieve a higher terrorist interception rate.

2. Comparison of Performance with and without the Plan Generation Software

The objective of this comparison is to highlight the importance of threat assessment before the planning process. Without threat assessment, the Plan Generation software simply uses range in the cost matrix for linear assignment without regarding the threat level. As a result, only around 50 percent of the terrorists were neutralized, as is shown in Figure 39.

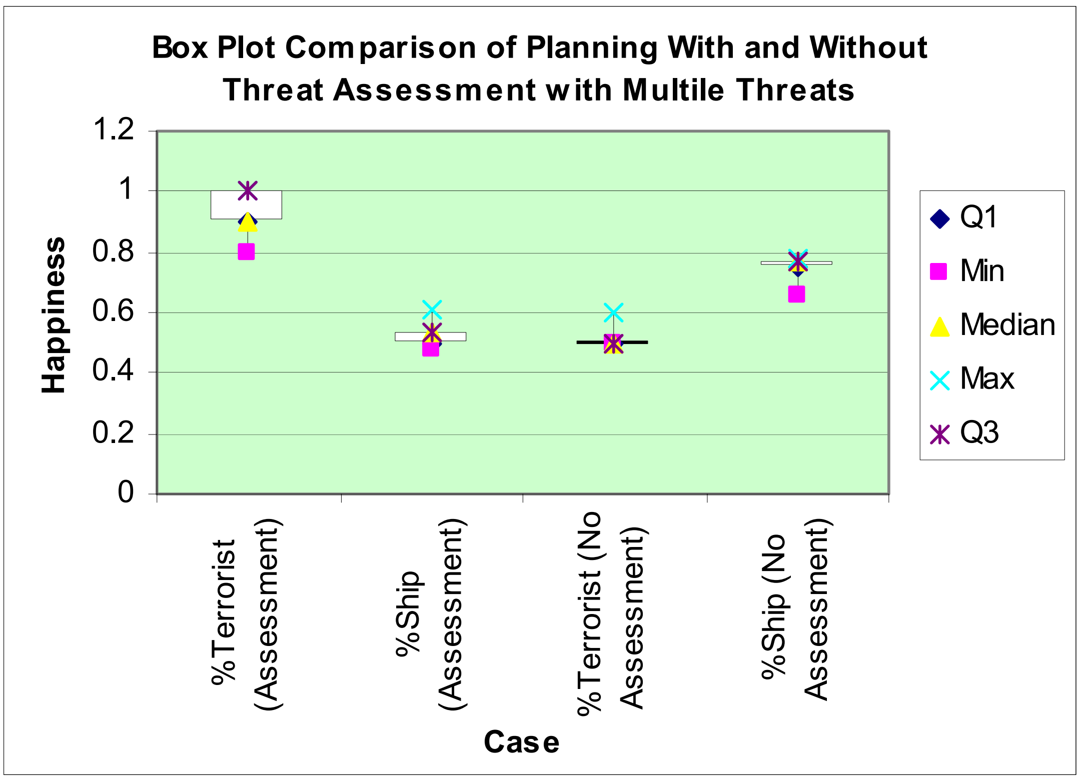


Figure 39. Comparison of Planned Profile with and without Threat Assessment

3. Computation Time Analysis

The times required to compute the contact course-of-action and to make a decision on own course-of-action are given in Figure 40. The timings collected were based on running the software on a Dell Inspiron Notebook with 1.67 MHz CPU and 1GB RAM. The time requirement increases almost linearly with an increase in the number of ships. Henceforth, the time required to compute one plan for one thousand ships in the Singapore Strait at any one time will take under two minutes. Since 60,000 ships transit through the Singapore Strait yearly [1], the ship time of arrival is approximately eight (8) minutes. As can be seen, the running of the plan for every ship arrival is feasible even on a low-end notebook. Therefore, the plan generation software is able to support near real-time planning for maritime interdiction.

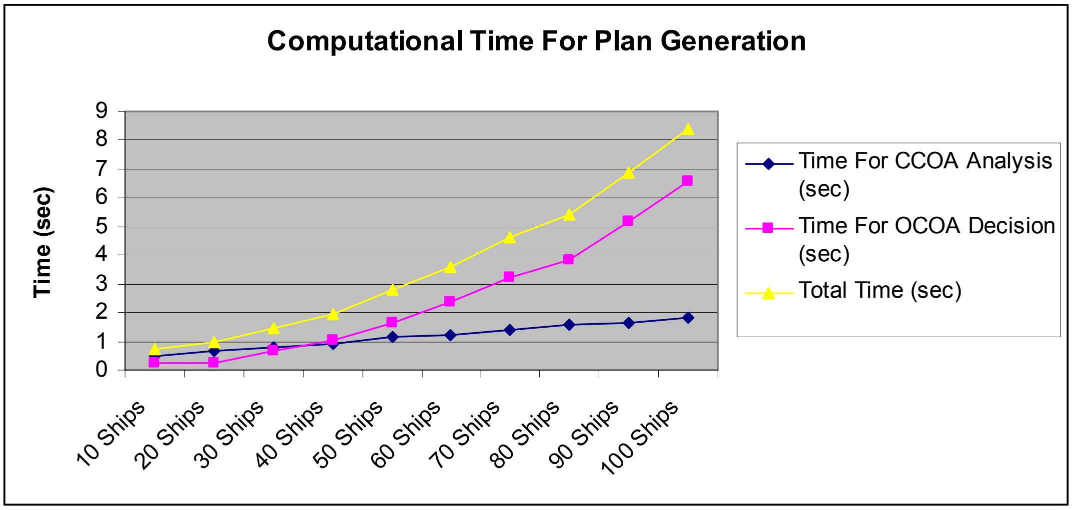


Figure 40. Computational Time for Plan Generation

G. CONCLUSION

This chapter has briefly described the enhancement of the simulator used in the SEA project. The architecture of the Plan Generation Software and several tests and surveys were also described. The tests show that the plan generated will allow a more effective and efficient deployment of interdiction resources. The amount of time required to generate the plan is able to support a near real-time application in the busy Singapore straits. Experienced naval officers and C2 engineers also verified that the threat assessment process resembles the mental processes that a human expert would use in the conduct of threat assessment. The chapter also shows that the probability estimate pattern can be used to represent a human mental pattern and can even be used to represent an atypical situation.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

This thesis shows that it is possible for the Boyd's OODA mental process [23], using conceptual blending theory [26], to develop course-of-action for maritime interdiction resources. The conceptual blending theory was implemented using the NPS CMAS Library [27] and a multi-agent system to model a human expert in the process of contact course-of-action identification.

The threat assessment model was developed based on Surface Warfare Threat Assessment [28]. During the model development process with expert surface warfare officers, we discovered that experts do not evaluate cues in isolation. A bio-inspired operator was used in the cue interpretation process. The thesis shows that the threat assessment model resembles the process of a human operator conducting surface threat assessment.

In addition, it shows that a group of probability estimates can be used to model the human mental pattern in a threat evaluation process. An individual probability estimate process autonomously based on local cue data can produce a global effect that induces the threat reasoning process.

It shows that a group of interdiction resources can be managed better with this Plan Generation Software as compared to a fixed path or nearest target approach. The performance of the plan allows the interception of terrorists with a high success rate without having the need to inspect more ships.

It has also been shown that a huge amount of contact course-of-action and own course-of-action can be generated through the conceptual blending theory process. Both sets of course-of-actions were evaluated through the use of conceptual blending to make a decision based on contact and interdiction resource analysis.

B. RECOMMENDATIONS

This thesis was an academic exercise that aimed to develop a concept demonstrator based on the conceptual blending theory to model an expert mental process through the OODA loop theory. Although the thesis demonstrated some success in applying the concept described in chapter two and has been well received by experienced naval officers and engineers, the factors of consideration are by no means comprehensive if this system is to be deployed in a real-world environment. A more detailed study based on available cues and classification of cues should be conducted. In addition, the process of goals generation and decision making can be improved by including goals such as logistical consideration, area of coverage influence, and environmental conditions. Logistical considerations may include the fuel and labor costs. Area of coverage refers to a consideration that all high-value units should be within the close proximity of one of the interdiction resources for deterrence and protection. Environmental conditions include the sea state and weather conditions.

In addition, the contact course-of-action analysis could be improved by Introducing mental simulation using intelligence agents to represent the terrorists. The terrorist behavior could be modeled as a function of interdiction resource positioning and environmental and traffic conditions before launching an operation. Ng [58] successfully applied intelligence agent technology to allow maritime terrorists to be adaptive to the environment and appear cognitively intelligent. His thesis features intelligence path-finding as a function of threat analysis. Such intelligent maritime terrorists allow the simulation into the enemy OODA mental loop process as suggested by Boyd [13]. That simulation might require a significance amount of computing power to allow real-time application.

Another enhancement might include learning agents to manage the interpretation of the cues in the threat assessment instead of a simple application of an expert’s knowledge. After a prediction, each tactic agent could compare its prediction to the actual results after positive identification so that adjustments could be made to improve the cue interpretation process. This would allow the system to accumulate its own experiences in addition to the expert's experience.

THIS PAGE INTENTIONALLY LEFT BLANK

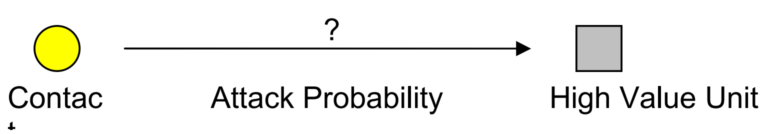
APPENDIX A: QUESTIONNAIRE FOR THREAT ASSESSMENT

Introduction

The purpose of this questionnaire is to determine how experienced surface warfare personnel conduct surface threat assessment based on a given set of cues.

Given the following cues, how will each state of cues affect your assessment of the attack probability of a contact against a high value unit? Please evaluate each state against each attack tactics by indicating:

– ‘+’ Increase likelihood little
– ‘++’ Increase likelihood more
– ‘-‘ Decrease likelihood little
– ‘-‘ Decrease likelihood more
– ‘O’ No effect.



What are the possible intentions of this contact against this high value unit? - Attempt to conduct Suicide Bombing? - Attempt to launch a RPG? - Attempt to Board? - Attempt leverage on its high inertial energy to cause damages? - Attempt leverage on its high chemical energy to cause

Your Background

Country: ________________________________

Rank: __________________

Name (optional): __________________

E-mail (optional): __________________

Number of years of Surface Warfare experience: _________

Sn	**Attack Tactics**	**Cues**											
		Too near (<0.2nm)			Very near (0.2nm – 1nm)			Near (1nm – 10nm)			Far (> 10nm)		
		Aiming at	Approaching (Closing)	Moving Away	Aiming at	Approaching	Moving Away	Aiming at	Approaching	Moving Away	Aiming at	Approaching	Moving Away
T1	Explosive Attack Against HVU												
T2	Short Range Weapon Attack Against HVU												
T3	Boarding Attack against mobile HVU												
T4	Huge Container Ship Attack against High Energy HVU												
T5	High Energy Ship Attack against High Energy HVU												
T6	Missile Attack Against HVU												
T7	Neutral Intention												

Sn	Attack Tactics	Cues																
		Crew Size			Behavior		Heavy		Small Arms		RPG		Missile Canister		Missile Equipment		Flammable Cargo	
		Too small	Too Big	Normal	Suspicious	Normal	yes	No	sighted	No	sighted	No	sighted	No	sighted	No	yes	no
T1	Explosive Attack Against HVU																	
T2	Short Range Weapon Attack Against HVU																	
T3	Boarding Attack against mobile HVU																	
T4	Huge Container Ship Attack against High Energy HVU																	
T5	High Energy Ship Attack against High Energy HVU																	
T6	Missile Attack Against HVU																	
T7	Normal																	

Sn	Attack Tactics	Cues													
		Craft Size		Speed		Origin		AIS		ELINT		HVU Type		HVU Type	
		Small	Big	yes	no	Southern island	SLOC	Error	Normal	Nav Radar	FCR	Mobile	Static	High Energy	Non High Energy
T1	Explosive Attack Against HVU														
T2	Short Range Weapon Attack Against HVU														
T3	Boarding Attack against mobile HVU														
T4	Huge Container Ship Attack against High Energy HVU														
T5	High Energy Ship Attack against High Energy HVU														
T6	Missile Attack Against HVU														
T7	Normal														

APPENDIX B: SUMMARY OF SURVEY RESULTS FOR THREAT ASSESSMENT

Sn	Attack Tactics	Cues											
		Too near (<0.2nm)			Very near (0.2nm – 1nm)			Near (1nm – 10nm)			Far (> 10nm)		
		Aiming at	Approaching (Closing)	Moving Away	Aiming at	Approaching	Moving Away	Aiming at	Approaching	Moving Away	Aiming at	Approaching	Moving Away
T1	Explosive Attack Against HVU	++	+	-	+	+	-	+	O	-	O	O	-
T2	Short Range Weapon Attack Against HVU	++	+	-	+	+	-	+	O	-	O	O	-
T3	Boarding Attack against mobile HVU	++	+	-	+	+	-	+	O	-	O	O	-
T4	Huge Container Ship Attack against High Energy HVU	++	+	-	+	+	-	+	O	-	O	O	-
T5	High Energy Ship Attack against High Energy HVU	++	+	-	+	+	-	+	O	-	O	O	-

Sn	Attack Tactics	Cues											
T6	Missile Attack Against HVU	--	-	O	++	+	O	+	+	O	+	+	-
T7	Neutral Intention	--	-	+	-	O	+	-	-	+	+	+	+

Sn	Attack Tactics	Cues																
		Crew Size			Behavior		Heavy		Small Arms		RPG		Missile Canister		Missile Equipment		Flammable Cargo	
		Too small	Too Big	Normal	Suspicious	Normal	yes	No	sighted	No	sighted	No	sighted	No	sighted	No	yes	no
T1	Explosive Attack Against HVU	++	--	-	++	-	++	O	-	O	+	O	--	O	--	O	+	O
T2	Short Range Weapon Attack Against HVU	O	--	O	++	-	-	O	-	O	++	O	--	O	--	O	-	O
T3	Boarding Attack against mobile HVU	--	++	O	++	-	-	O	++	--	-	O	--	O	--	O	-	O
T4	Huge Container Ship Attack against High Energy HVU	--	++	O	++	-	O	O	++	-	-	O	--	O	--	O	-	+
T5	High Energy Ship Attack against High Energy HVU	--	++	O	++	-	O	O	++	-	-	O	--	O	--	O	+	-
T6	Missile Attack Against HVU	--	O	O	O	-	O	O	-	O	-	O	++	-	++	-	-	O
T7	Normal	-	-	+	--	+	-	O	-	+	--	+	--	O	--	O	O	O

Sn	**Attack Tactics**	**Cues**													
		Craft Size		Speed		Origin		AIS		ELINT		HVU Type		HVU Type	
		Small	Big	yes	no	Southern island	SLOC	Error	Normal	Nav Radar	FCR	Mobile	Static	High Energy	Non High Energy
T1	Explosive Attack Against HVU	+	-	+	O	+	O	+	O	O	-	O	O	O	O
T2	Short Range Weapon Attack Against HVU	+	-	+	O	+	O	+	O	O	-	O	O	O	O
T3	Boarding Attack against mobile HVU	+	-	+	O	+	O	+	O	O	-	+	-	--	O
T4	Huge Container Ship Attack against High Energy HVU	-	+	+	O	+	O	+	O	O	-	O	O	+	-
T5	High Energy Ship Attack against High Energy HVU	-	+	+	O	+	O	+	O	O	-	O	O	+	+
T6	Missile Attack Against HVU	-	+	-	O	+	O	+	O	O	++	O	O	O	O
T7	Normal	O	O	-	O	O	O	-	+	+	--	O	O	O	O

APPENDIX C: QUESTIONNAIRE FOR VERIFYING THE PLAN GENERATION MODEL MODELS FOR MARITIME INTERDICTION

Introduction

The purpose of this questionnaire is to verify the plan generation models developed in the thesis on a multi-agent system (MAS) for planning the deployment of maritime interdiction asset to conduct close surveillance and interdiction mission along a busy sea lane. The plan generation process include the processes of unfriendly course of action identification, need identification, patrol craft effectiveness assessment and patrol craft to track assignment.

In order to achieve this goal, the MAS has three main objectives:

1. To help the human operator monitor high volume traffic conditions in the port and surrounding waterways in order to identify suspicious shipping and associated course of action.

2. To help the human operator to focus on the higher priority track through adaptive display of the situational picture and track prioritization.

3. To help the human operator to generate assignment plan for the maritime interdiction asset in order to conduct close surveillance or interdiction mission.

The thesis is only a preliminary investigation into the modeling of plan generation of maritime interdiction process. The models are not considered exhaustive as they only use a very small and basic set of parameters and attributes. It is expected that there will be many more parameters that may be used by human experts in determining and analyzing of the hypothesis generated.

The focus of this validation will only be on the hypothesis and plan generation only. The display is only used to model a possible vessel traffic information system.

Your Background

Country: ________________________________

Rank: ___________________

Name (optional): ___________________

E-mail (optional): __________________

Number of years of Surface Warfare experience: _________

Number of years in C2 system development: (For contractor): ___________

1	Do you use observation-orientation-decision-action loop theory as your mental process in making decision in a combat environment?	Yes	Not Sure	No
2	Does the mental picture formed by the computer resemble the mental picture formed by human expert?	Similar	Not Sure	Different
3	Does the computer produce meaningful attack hypothesis mental picture with the given cues?	Yes	Not Sure	No
4	How does the computer perform in identifying terrorist activities?	Good	Not Sure	Bad
5	How does the computer perform in own course-of-action analysis?	Good	Not Sure	Bad
6	How does the computer perform in deciding own course-of-action?	Good	Not Sure	Bad
7	Will such a system be useful to assist the human expert in planning for maritime interdiction mission?	Yes	Not Sure	No
8	Can you tell the difference if the probability estimate pattern is generated by computer instead of human being?	Yes	Not Sure	No
9	Will adaptive displace be useful for decision-making?	Yes	Not Sure	No
10	How does the computer perform in generating adaptive display?	Good	Not Sure	Bad

Comment:

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D: RESULTS OF QUESTIONNAIRE FOR VERIFYING THE PLAN GENERATION MODEL MODELS FOR MARITIME INTERDICTION

Do you use observation-orientation-decision-action loop theory as your mental process in making decision in a combat environment?	Yes 100%	Not Sure 0%	No 0%
Does the mental picture formed by the computer resemble the mental picture formed by human expert?	Similar 80%	Not Sure 20%	Different 0%
Does the computer produce meaningful attack hypothesis mental picture with the given cues?	Yes 80%	Not Sure 20%	No 0%
How does the computer perform in identifying terrorist activities?	Good 80%	Not Sure 20%	Bad 0%
How does the computer perform in own course-of-action analysis?	Good 80%	Not Sure 20%	Bad 0%
How does the computer perform in deciding own course-of-action?	Good 100%	Not Sure 0%	Bad 0%
Will such a system be useful to assist the human expert in planning for maritime interdiction mission?	Good 100%	Not Sure 0%	Bad 0%
Can you tell the difference if the probability estimate pattern is generated by computer instead of human being?	Good 80%	Not Sure 20%	Bad 0%
Will adaptive displace be useful for decision-making?	Yes 100%	Not Sure 0%	No 0%
How does the computer performs in generating adaptive display?	Good 80%	Not Sure 20%	Bad 0%

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

[1] Maritime and Port Authority of Singapore (MPA, "Singapore Maritime Industry Enjoys Good Performance in 2006," http://www.mpa.gov.sg/infocentre/newsreleases/2007/nr070110.htm (accessed January 10, 2007).

[2] S. Bateman, C. Z. Raymond and J. Ho, "Safety and Security in the Malacca and Singapore Straits: An Agenda for Action," Institute of Defence and Strategic Studies Policy Paper, May 2006.

[3] Maritime and Port Authority of Singapore (MPA), "Singapore Once Again Recognised as the Best Seaport in Asia by Industry Players," http://www.mpa.gov.sg/infocentre/newsreleases/2007/nr070425.htm (accessed April 25, 2007).

[4] Maritime and Port Authority of Singapore (MPA), "Singapore: International Maritime Centre," http://www.mpa.gov.sg/aboutmpa/portofsg/port.htm (accessed October 11, 2007).

[5] C. Z. Raymond, "Piracy in Southeast Asia: New Trends, Issues and Responses" *Harvard Asia Quarterly*. Volume IX, No. 4. Fall 2005, http://www.asiaquarterly.com/content/view/30/ (accessed October 11, 2007).

[6] Maritime and Port Authority of Singapore (MPA), "Maritime and Port Security," http://www.mpa.gov.sg/maritimeportsecurity/maritime_security.htm (accessed October 11, 2007).

[7] Wikipedia, "Automatic Identification System," http://en.wikipedia.org/wiki/Automatic_Identification_System (accessed September 25, 2007).

[8] Navigation Centre, "What AIS Broadcasts," http://www.navcen.uscg.gov/enav/ais/what_AIS_broadcasts.htm (accessed September 25, 2007).

[9] MPA, "Mandatory Ship Reporting System in the Straits Of Malacca and Singapore: Straitrep," Port Marine Circular no. 65, October 12, 1998.

[10] MediaCorp News, "Indonesia navies launch sea surveillance System, Channel news Asia," May 27, 2005, http://www.channelnewsasia.com/stories/singaporelocalnews/view/149677/1/.htl (accessed September 1, 2007).

[11] Catherine Zara Raymond, "Maritime Security: The Singaporean Experience Draft," Institute of Defence and Strategic Studies Singapore, December 2005.

[12] S. MacPhee, "Rationale for a Marine Electronic Highway Program in the Mediterranean Sea," June 2005, Advisory Committee on Protection of the Sea (ACOPS), Concept Paper.

[13] J. Boyd, Organic Design for Command and Control, 1987.

[14] Maritime and Port Authority of Singapore (MPA), "MPA'S Roles," http://www.mpa.gov.sg/aboutmpa/mparoles/roles.htm (accessed October 11, 2007).

[15] Singapore Police Force (SPF), "Police Coast Guard (PCG)," http://www.spf.gov.sg/abtspf/pcg.htm#dept (accessed October 11, 2007).

[16] Republic of Singapore Navy (RSN), http://www.mindef.gov.sg/navy (accessed October 11, 2007).

[17] T. Rajan, "Spartan USVs for Singapore's Navy," Defence Industry Daily, May 18, 2005, http://www.defenseindustrydaily.com/spartan-usvs-for-singapores-navy-0540 (accessed October 15, 2007).

[18] A. Maguer, D. Gourmelon, M. Adatte, and F. Dabe, "Flash and/Or Flash-S Dipping Sonars on Spartan Unmanned Surface Vehicle (USV): A New Asset for Littoral Waters," Turkish International Conference on Acoustics, July 2005.

[19] T. Rajan, "Unmanned Craft to Play Bigger Role in Maritime Security," *The Straits Times*, pH10, June 8, 2007.

[20] Reeves (2005) Maritime military decision making in environments of extreme information ambiguity.

[21] Applied Technology Institute (ATI), "ATI's Multi-Target Tracking and Multi-Sensor Data Fusion Course," http://www.aticourses.com/radar_tracking_kalman.htm (accessed October 15, 2007).

[22] I. Jouny, "Target identification using multi-radar fusion," SPIE, Vol. 6566, p. 65660M, April 2007.

[23] E. Charlwood, R. Griffiths and Max Buttinger, "Acquisition, Tracking, and Pointing XIV," SPIE, Vol. 4025, pp. 42-51, July 2000.

[24] J. Suo and X. Liu, "Fusion of Radar and AIS Data," 7th International Conference on Signal Processing Proceedings (ICSP'04), pp. 2604-2607, 2004.

[25] K. S. Tan, “A multi-agent system for tracking the intent of surface contacts in ports and waterways,” M.S. thesis, Naval Postgraduate School, 2005.

[26] G. Fauconnier and M. Turner, “The Way We Think: Conceptual Blending and the Mind's Hidden Complexities,” ISBN-10: 046508785X, April 2002.

[27] Naval Postgraduate School, “CMAS System Library User’s Guide,” Revision 1.1, November 2004.

[28] M. J. Liebhaber and B. A. Feher, “Surface Warfare Threat Assessment Requirements Definition,” Technical Report 1887, August 2002.

[29] Naval Postgraduate School (NPS) Systems Engineering and Analysis (SEA) Integrated Project, “Port Security Strategy 2012” (PSS12), Spring 2007.

[30] S. Coulson 1997. Semantic leaps: The role of frame-shifting and conceptual blending in meaning construction. Ph.D. dissertation, Cognitive Science, University of California, San Diego.

[31] B. E. Ozkan, Autonomous agent-based simulation of a Model simulating the human air-threat assessment process, M.S. thesis, Naval Postgraduate School, Monterey, California, March 2004.

[32] J. E. Hiles, 2004, “IAGO Project and Development of Compound Agents,” Proceedings of the 2004 Winter Simulation Conference.

[33] Science Encyclopaedia, “Classical Decision theory,” http://science.jrank.org/pages/10976/Rational-Choice-Classical-Decision-Theory.html (accessed October 21, 2007).

[34] V. J. Neumann and O. Morgenstern, *Theory of Games and Economic Behavior*, Princeton, NJ: Princeton University Press, 1953.

[35] W. B. Arthur, “Inductive Reasoning and Bounded Rationality,” *American Economic Review*, pp. 406-411, 1994.

[36] H. A. Simon, The Sciences of the Artificial. Cambridge, MA: MIT Press, 1981.

[37] Tversky, A. and D. Kahneman, “Judgment under Uncertainty: Heuristics and Biases,” *Science* Vol. 185, pp. 1124-1131, 1974.

[38] Wikipedia, “Naturalistic decision making,” October 18, 2007, http://en.wikipedia.org/wiki/Naturalistic_decision_making (accessed October 27, 2007).

[39] E. Salas and G. Klein, “Linking Expertise and Naturalistic Decision Making,” Lawrence Erlbaum Associates, ISBN 0-8058-3538-5, 2001.

[40] G. Klein, *Sources of Power: How People Make Decisions*, Cambridge, MA: MIT Press, 1998.

[41] D. Kunder, “Event prediction for modeling mental simulation in naturalistic decision making,” Ph.D. dissertation, Naval Postgraduate School, December 2005.

[42] A. Buss, 1996, Modeling With Event Graph.

[43] A. Buss, 2000, Component-Based Simulation Modeling.

[44] A. Buss, 2001, Technical Notes: Basic Event Graph Modeling.

[45] A. Buss, 2002, Component Based Simulation Modeling With Simkit.

[46] A. Buss, and P. J. Sanchez, 2002, Building Complex Models with LEGOS (Listener Event Graph Objects).

[47] A. Buss and P. J. Sanchez, Simple Movement and Detection in Discrete Event Simulation, 2005.

[48] D. Vakas, J. Price, H. Blacksten and C. Burdick, “Commander Behavior and Course of Action Selection in JWARS,” Proceedings of the 33rd conference on winter simulation, pp. 697–705, 2001.

[49] W. H. Lunceford, R. Richardson, R. Alexander, G. Turner, Tarbox, G.H., “Course of Action Analysis.

[50] J. Hanna, J. Reaper, T. Cox and M. Walter, “Course of Action Simulation Analysis,” 10th International Command and Control Research and Technology Symposium, The Future of C2, 2005.

[51] J. A. Sokolowski, “Representing Knowledge and Experience in RPDAgent,” 2003.

[52] J. A. Sokolowski, “Enhanced Military Decision Modeling Using a Multi-Agent System Approach,” 2003.

[53] A. Ercetin, “Operational-Level Naval Planning Using Agent-Based Simulation,” M.S. thesis, Naval Postgraduate School, 2001.

[54] G. Rohan and P. Chalk, “Terrorist Tactics and Targets,” *Counter Terrorism*, Chap. 3, 2nd ed., Jane’s Information Group, October 2002.

[55] G. Rohan, “The Asymmetric Threat from Maritime Terrorism,” Jane’s Navy International, 24-29, October 2001.

[56] Z. C. Raymond, “Maritime Terrorism in Southeast Asia: Potential Scenarios,” *Terrorism Monitor*, Vol. IV, Issue 7, April 6, 2006.

[57] J. Munkres, “Algorithms for the Assignment and Transportation Problems,” *Journal of the Society for Industrial and Applied Mathematics*, Vol. 5, No. 1 (March 1957), pp. 32-38.

[58] C. W. Ng, “Discrete event simulation with agents for modeling of dynamic asymmetric threats in maritime security,” M.S. thesis, Naval Postgraduate School, December 2007.

[59] R. G. Sargent, “Verification and Validation of Simulation Models,” Proceedings of the 1998 Winter Simulation Conference, 1998.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. John Hiles
   Naval Postgraduate School
   Monterey, California

4. Paul Shebalin
   Naval Postgraduate School
   Monterey, California

5. Anthony Ciavarelli
   Naval Postgraduate School
   Monterey, California

6. Curtis Blais
   Naval Postgraduate School
   Monterey, California